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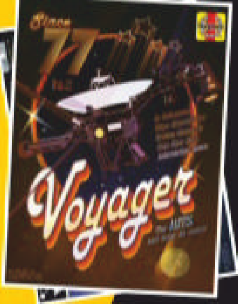

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Neptune is strangely warm considering its distance

Welcome

One moment it wasn't, the next it was. That's how *most* cosmologists believe our universe sprang into existence. Some 13.8 billion years ago, and like the rapid inflation of a balloon, it's suspected that the galaxies, planets, stars, dust and gas all originated from a point smaller than the size of an electron - the subatomic particle found in the atom. The event we know today as the Big Bang.

You'll notice that I used the word most there - that's because some astrophysicists don't believe in the theory. They suspect that space and time originated via some other means, and that the Big Bang really wasn't the beginning.

Whatever theory you believe in, there's plenty to learn about how our universe sprang into existence over on page 16 as **All About Space** chats to the scientists attempting to unravel its many mysteries once and for all.

Elsewhere this issue, we chat to former NASA software engineer Margaret Hamilton about the trials and tribulations of developing the software on board the Apollo missions to the Moon. There's trouble on board the International Space Station, a puzzle at Neptune is solved, plus more this month.

If you haven't seen them already over on our social channels, don't forget to look out for the exclusive **All About Space** mission patches, which will be making their way to you over the next few months.

Gemma Lavender
Editor-in-Chief

Our contributors include...

Andrew May
Space science writer
The Big Bang might not have been the very beginning, as we discover in Andrew's latest report. Turn to page 16 for the full details

Abigail Beall
Space science writer
The cosmos could be one big Schrödinger's Cat – both dead and alive – according to a brand-new view of the universe. Find out more on page 46

Margaret Hamilton
Former NASA computer scientist
Margaret unfolds how the challenges, sacrifice and hard work helped her to develop the Apollo onboard computers

David Crookes
Space reporter
What does the UK leaving the European Union mean for UK astronomy and space exploration? David chats to space agency officials for the answer

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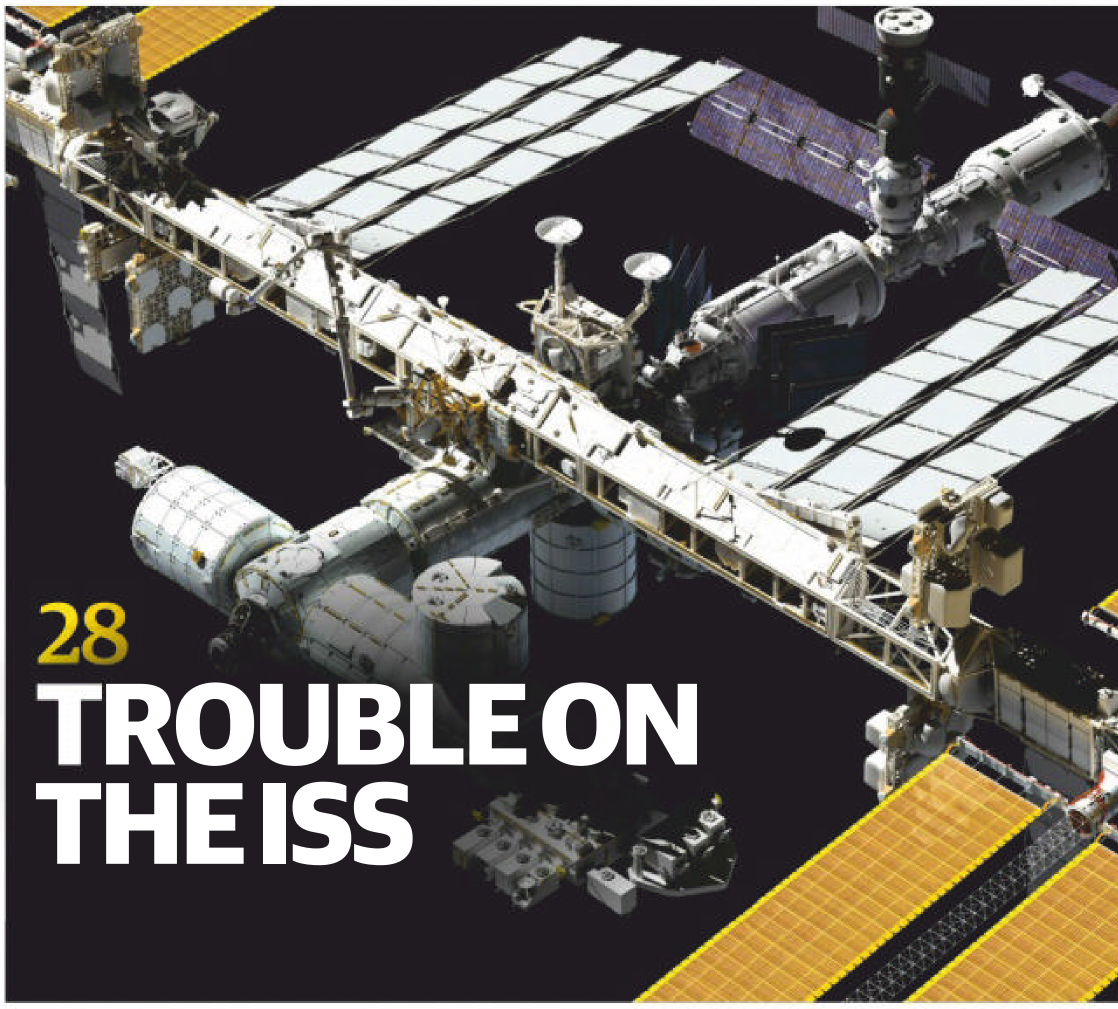

FREE SPACE ROCKS BUNDLE

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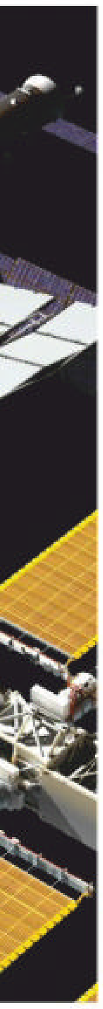

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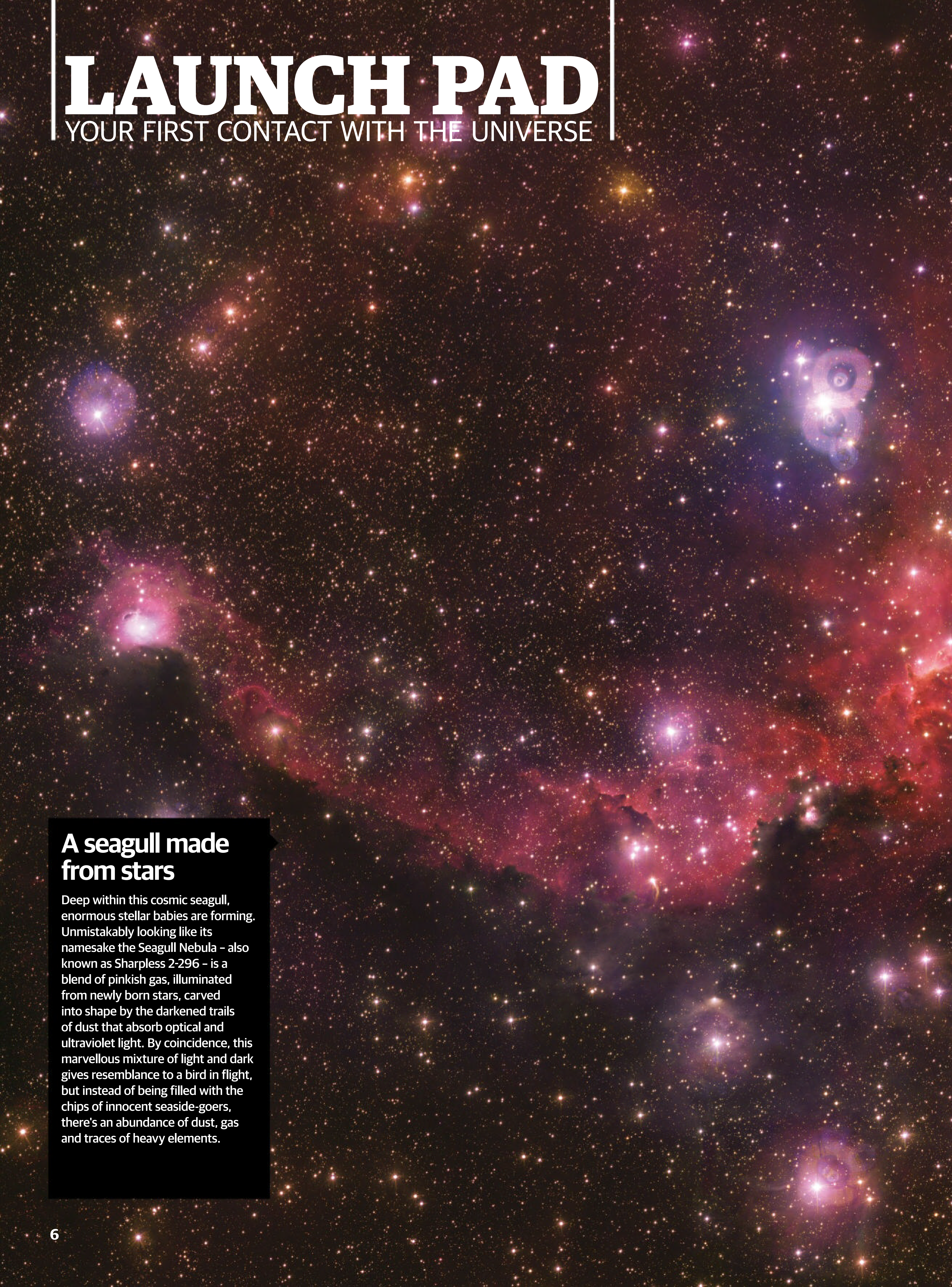

A seagull made from stars

Deep within this cosmic seagull, enormous stellar babies are forming. Unmistakably looking like its namesake the Seagull Nebula – also known as Sharpless 2-296 – is a blend of pinkish gas, illuminated from newly born stars, carved into shape by the darkened trails of dust that absorb optical and ultraviolet light. By coincidence, this marvellous mixture of light and dark gives resemblance to a bird in flight, but instead of being filled with the chips of innocent seaside-goers, there's an abundance of dust, gas and traces of heavy elements.

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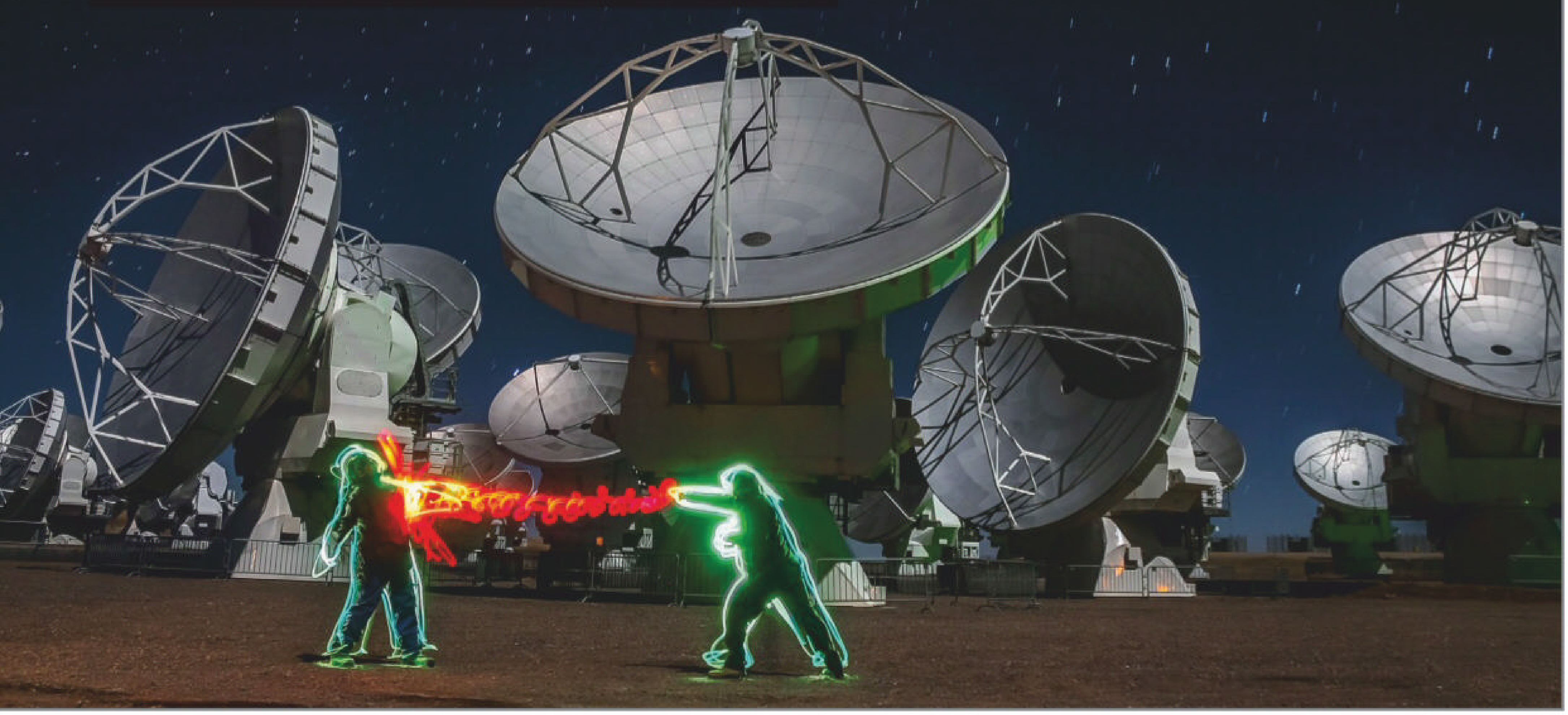
Ready, Player One

The European Southern Observatory (ESO) uses its global network of telescopes to capture the best pictures of the universe, but there's no harm in having a bit of fun once in a while. Here is a scenario that bares a striking resemblance to the video game Mortal Kombat.

The sight of two opponents facing off in front of picturesque background will make gamers of the 1990s reminisce. In this picture, there are two ESO staff members pretend-fighting – with the help of some special effects – in front of the Atacama Large Millimeter Array in Chile.



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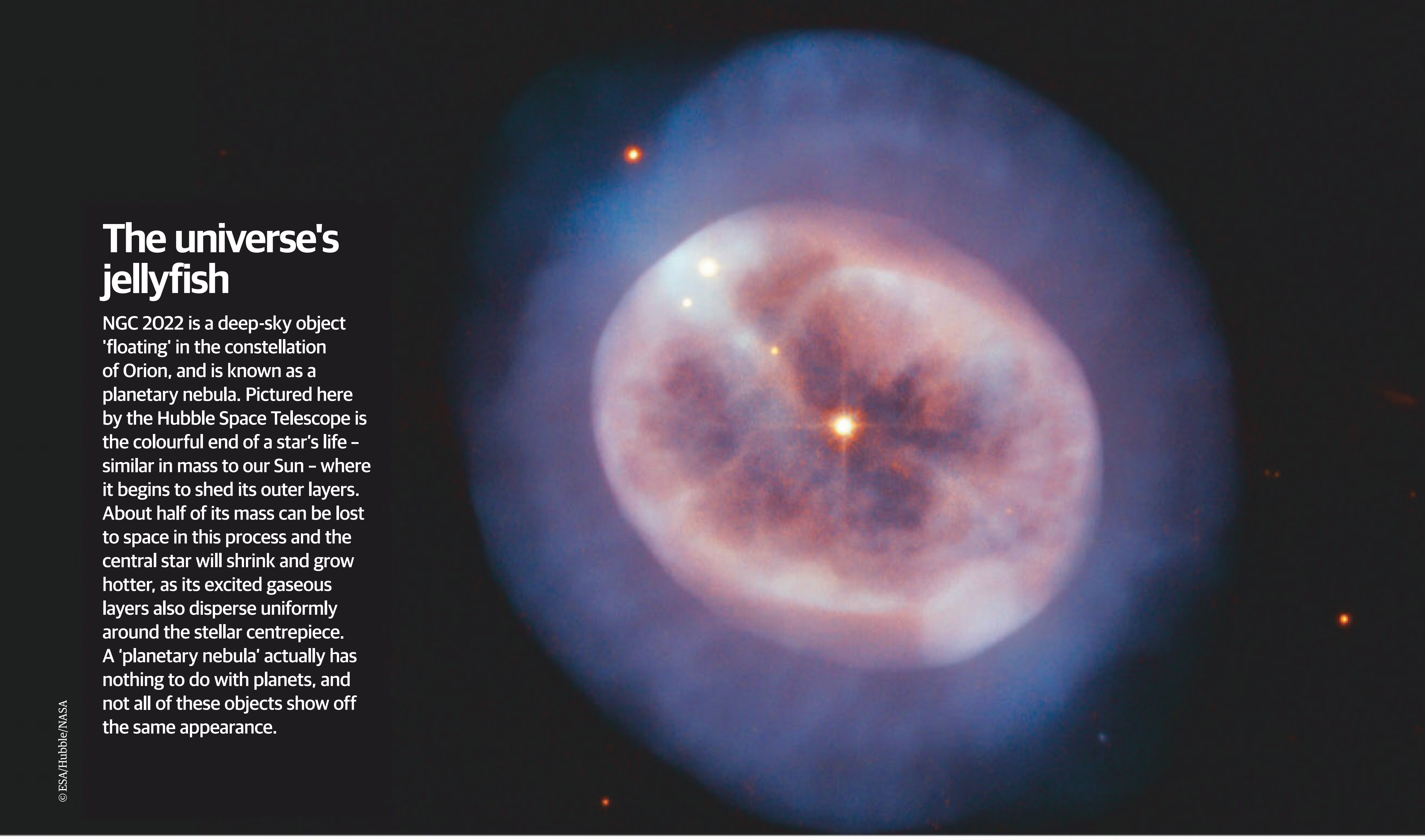
Views of space, from space

There's no better place to stare up at the shining stars and gaze upon the dusty band of the Milky Way stretching overhead than from the International Space Station (ISS). The astronauts work very hard on the Earth-orbiting outpost with countless experiments and science communication activities, so it is only fair that they can take a minute to observe and photograph the unique view of our planet's glowing limb that billions of people don't have the privilege to see.

In the same vein, views of the Moon appear even better on the ISS. As the station flew 430 kilometres (270 miles) over the South Pacific Ocean, they snapped a shot of our lunar companion.



The universe's jellyfish

NGC 2022 is a deep-sky object 'floating' in the constellation of Orion, and is known as a planetary nebula. Pictured here by the Hubble Space Telescope is the colourful end of a star's life – similar in mass to our Sun – where it begins to shed its outer layers. About half of its mass can be lost to space in this process and the central star will shrink and grow hotter, as its excited gaseous layers also disperse uniformly around the stellar centrepiece. A 'planetary nebula' actually has nothing to do with planets, and not all of these objects show off the same appearance.

© ESA/Hubble/NASA

Ding ding, the Dragon delivery is here

The way ISS astronauts look at the incoming SpaceX Dragon cargo vehicle as it approaches the station must be similar to how we look out of the window, waiting for the delivery person to arrive. Instead of waiting for a large pepperoni pizza though, these astronauts receive more vital supplies such as fresh drinking water, more food and the latest scientific experiments. These not only provide unique results but must also supply a mental benefit to the astronauts.

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A new look at Jupiter

NASA/ESA's Hubble Space Telescope always likes to check up on the outer Solar System. On 27 June 2019, the spacecraft took this picture of Jupiter, but do you recognise anything different about it?

For the keen-eyed, you may notice that there is a much more intense colour range in the Jovian clouds than previously seen. Astronomers believe this could change could hold some interesting clues to what is happening in king of the Solar System's atmosphere.

An army of ancient stars

To the unaided eye, Omega Centauri could easily be confused with a faint star. But it isn't until you get a closer inspection that you see it is in fact 10 million stars, all brought together by gravity in what is known as a globular cluster. Taken by Wouter van Reeven, one of the European Space Agency's software engineers at the European Space Astronomy Centre in Madrid, Spain, this magnificent image reveals globular clusters in their true form: devoid of any gas and dust, as all material has been fused into the large number of stars shown in the tight stellar gathering.

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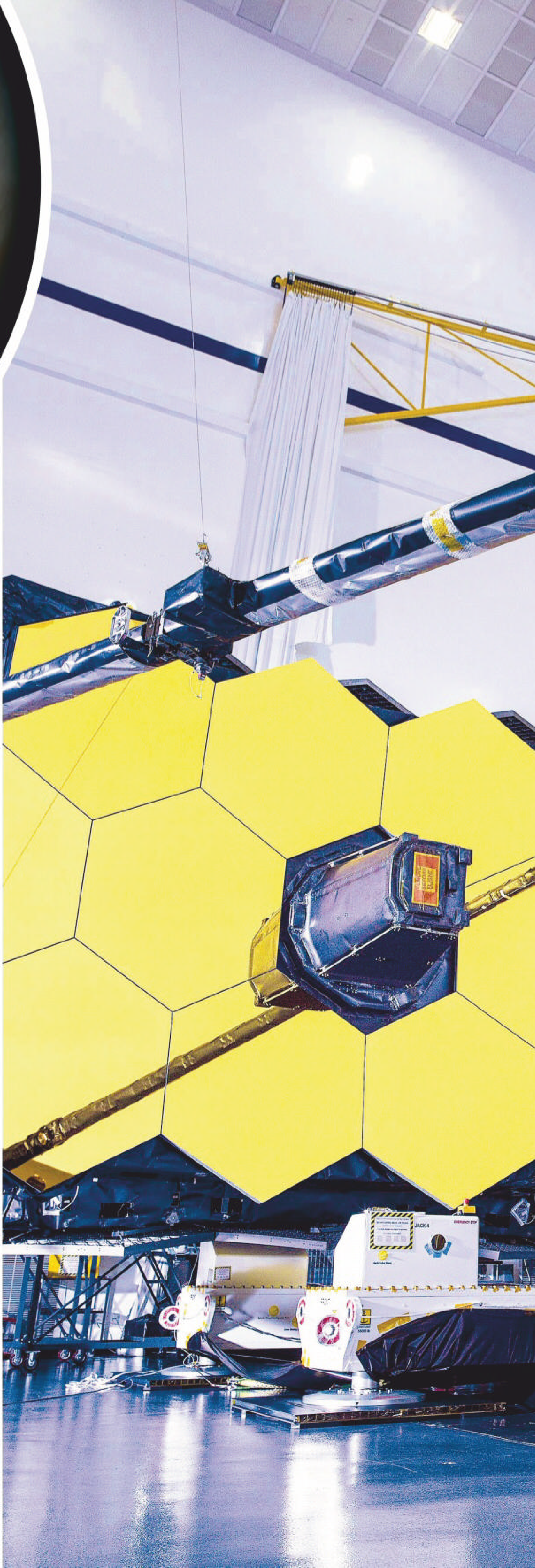
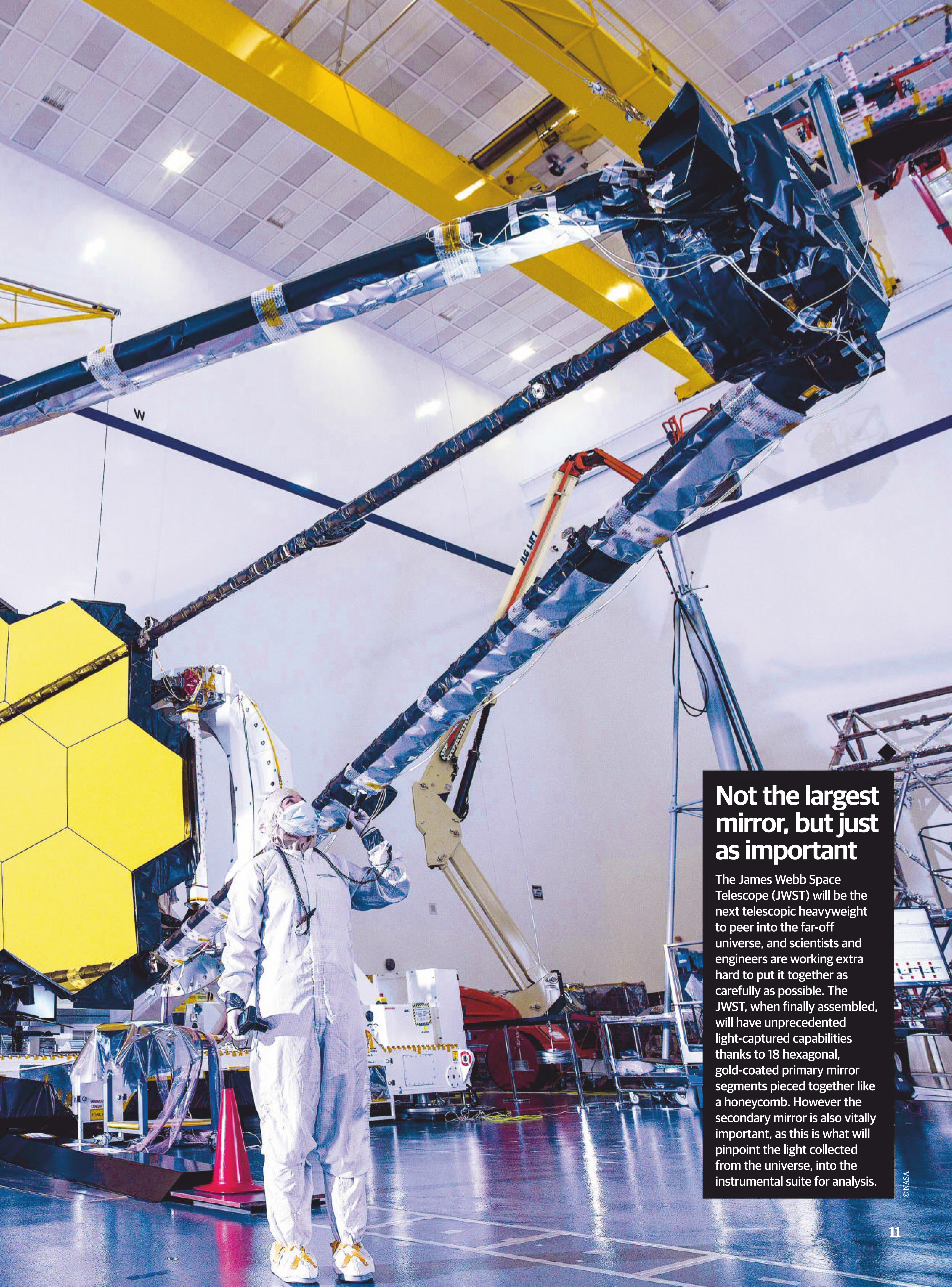




Not the largest mirror, but just as important

The James Webb Space Telescope (JWST) will be the next telescopic heavyweight to peer into the far-off universe, and scientists and engineers are working extra hard to put it together as carefully as possible. The JWST, when finally assembled, will have unprecedented light-captured capabilities thanks to 18 hexagonal, gold-coated primary mirror segments pieced together like a honeycomb. However the secondary mirror is also vitally important, as this is what will pinpoint the light collected from the universe, into the instrumental suite for analysis.

©NASA

Jupiter's strange core may have been forged by a colossal head-on crash

Words by **Chelsea Gohd**

About 4.5 billion years ago a young Jupiter collided head-on with a planetary embryo ten-times more massive than Earth. This giant impact formed Jupiter's dilute core, which contains hydrogen and helium, one new study suggests.

Before NASA's Juno mission launched to orbit and study Jupiter, scientists thought that the planet's core was dense and compact. "Astronomers assumed that Jupiter has a small compact core with a mass ranging from five to 20 Earth masses," lead study author Shangfei Liu of Sun Yat-sen University in Zhuhai, China, said in an email to **Space.com**.

This was assumed because Jupiter started off as a rocky and icy planetary embryo. However, studies using data from Juno found that the planet has an extended, dilute core – a core that is not only made up of rocky material and ice, but also hydrogen and helium. This "also means there is no sharp transition between the core and the envelope, as we previously envisioned from planet formation theory," Liu said. This dilute core is something that scientists determined could not form naturally.

"That's why we came up with the impact idea: Jupiter was smacked head-on by another massive planetary embryo shortly after its formation," Liu said. "Such a catastrophic collision destroyed Jupiter's primordial compact core, and a dilute core-like structure was formed." The cores of both the young Jupiter and the planetary embryo merged in this violent impact, the authors of this study suggest. The materials from both of these cores partially mixed with Jupiter's gaseous envelope, which can still be detected in the planet's structure today.

When Jupiter began building the massive, gaseous envelope that surrounds its core, "its mass increased about 30 times in a fraction of a million years," Liu said. This process, known as the runaway gas accretion stage, disturbed planetary embryos that were developing nearby.

"Through computational simulations we show that there is at least a 40 per cent chance that Jupiter would collide with another planetary embryo in the next few million years," Liu added.

The team determined that the developing planet that collided with Jupiter must have been about ten-times the mass of the Earth, because "smaller impactors cannot penetrate Jupiter's massive envelope", Liu said. Additionally the collision must have been head-on, because if the object didn't hit Jupiter directly it would slowly sink toward the centre instead of destroying the planet's core, as it would have less impact energy.

Elon Musk floats 'Nuke Mars' idea again

Words by **Michael Wall**

Nuking Mars is still on Elon Musk's wish list, it would seem. Four years ago the SpaceX founder and CEO went on *The Late Show With Stephen Colbert* and discussed a strategy for making the Red Planet more livable: detonating nuclear bombs over its poles. The explosions would vaporise a fair chunk of Mars' ice caps, liberating enough water vapour and carbon dioxide - both potent greenhouse gases - to warm up the planet substantially, the idea goes.

This terraforming concept is apparently still bouncing around in Musk's head, because on 15 August he tweeted, seemingly unprompted: "Nuke Mars!" A few hours later he followed up with another tweet: "T-shirt soon."

If Musk is serious about nuking the Red Planet - and it's possible that he's not - he'll have to overcome significant skepticism. For starters, many scientists and exploration advocates have concerns about any terraforming efforts: do we have the right to fundamentally transform another world - especially one that might host its own uniquely adapted life, even today - for our own purposes?

In addition, the strategy might not even work. A 2018 study published in the prestigious journal *Nature Astronomy* concluded that Mars doesn't harbor enough CO_2 today to achieve significant warming, even if all the stuff were liberated into the atmosphere. "As a result, we conclude that terraforming Mars is not possible using present-day technology," the researchers wrote.

But the nuke concept could be worse than ineffectual, some scientists have said. Namely it could backfire, ushering in a "phenomenon known as 'nuclear winter' - akin to the asteroid impact that killed off the dinosaurs - wherein you generate so much dust and particles that they literally block out a significant portion of the incoming sunlight, cooling down the planet," climate scientist Michael Mann of Penn State University told *U.S. News and World Report*.

© Daein Ballard

Nuclear weapons might transform Mars into an Earth-like planet

© NASA, ESA

NASA's Artemis lander to be made in Alabama's 'Rocket City'

Words by **Hanneke Weitering**

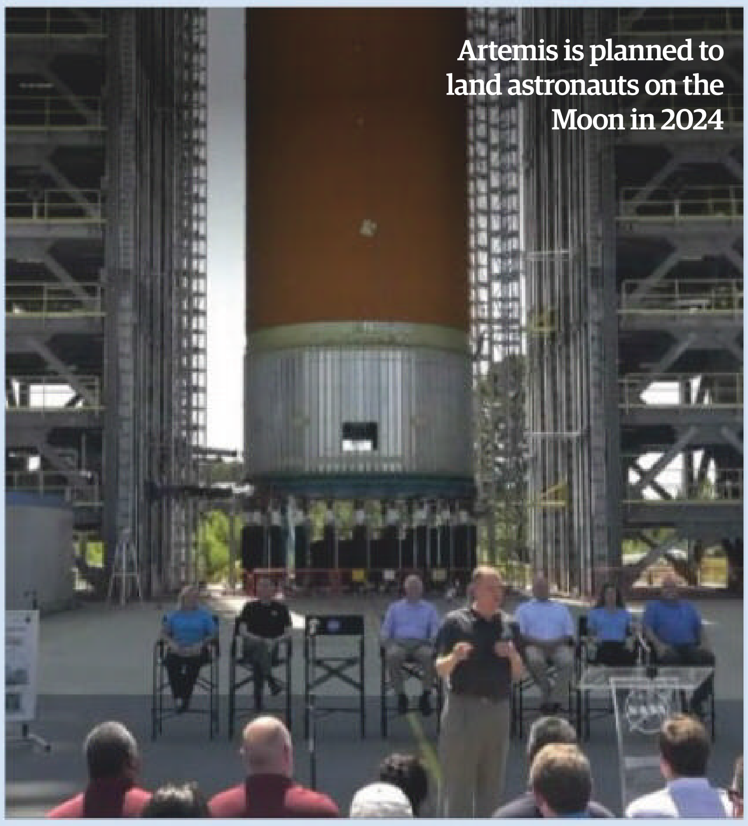
The lunar lander that will bring astronauts to the Moon in 2024 will be born in Alabama's 'Rocket City', NASA announced on 16 August.

NASA's Marshall Space Flight Center (MSFC) in Huntsville will lead the development of a lunar lander for the agency's Artemis program, which aims to land astronauts on the Moon in 2024. Huntsville is known as 'Rocket City' due to its long history of building rockets for NASA. MSFC is also currently building the Space Launch System megarocket that will launch NASA's Artemis missions.

According to NASA administrator Jim Bridenstine the centre was selected to be in charge of the lunar lander because of its extensive experience with propulsion systems, which will be crucial for executing safe landings and liftoffs from the lunar surface.

"There is no place in the world that is more experienced" in propulsion, Bridenstine said during a news briefing at the centre. As he spoke Bridenstine stood in front of a massive 45-metre (149-foot) tall structural test component for the Space Launch System, which will stand about 98 metres (322 feet) tall when fully assembled.

Bridenstine also announced that the new human landing system will be managed by Lisa Watson-Morgan, the former deputy engineering director of MSFC. A 'Rocket City' native who has worked her way up the ranks at MSFC for the last 15 years, Watson-Morgan will oversee the project that will land "the first woman and the next man on the Moon," Bridenstine said.



Artemis is planned to land astronauts on the Moon in 2024

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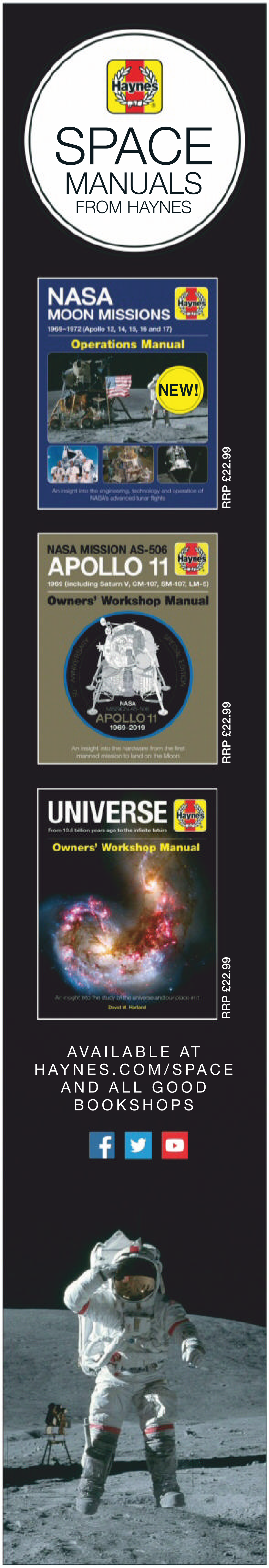
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Astronomers recorded a brightness increase in Sgr A*

© ESO, ESA/Hubble

Something weird is happening to the Milky Way's black hole

Words by **Meghan Bartels**

Astronomers have been watching the black hole at the centre of our galaxy for 20 years, and in May they saw something they'd never seen before.

Technically they aren't watching the black hole itself, which scientists call Sagittarius A*, or Sgr A*. Instead they're looking at the matter around that black hole. When the Milky Way's black hole is more active than usual, that event horizon becomes brighter as it heats up due to friction. Usually Sgr A* is pretty calm for a black hole, but in May that changed, according to new research.

"The black hole is always variable, but this was the brightest we've seen in the infrared so far," Tuan Do, an astronomer at the University of California, Los Angeles, and lead author of the new study, said on Twitter. "It was probably even brighter before we started observing that night!"

That hypothesis is based on the fact that when the astronomers focused on the area on 13 May, they only saw relatively high brightness decreasing, suggesting that the black hole had passed an unknown peak that was even brighter. According to the new research, the recent flare brought Sgr A* to twice the brightness of the highest previous measurement to date.

Do and his colleagues made the observations using the Keck telescopes on the summit of Mauna Kea in Hawaii. That instrument can see the world in near infrared light, which encompasses wavelengths a bit longer than those our eyes can see.

They think the black hole flare may have been caused by the close passage of either a star called S0-2 last year or a dusty object called G2 in 2014.

Scientists create millions of virtual universes

Words by **Passant Rabie**

Observing the universe through telescopes can provide some clues as to how galaxies came to be, but looking at millions of virtual universes on a supercomputer gave scientists more insight into galaxy formation and the role that dark matter plays in it.

A team of scientists from the University of Arizona generated millions of universe simulations, each following a different theory of galaxy formation. Every simulated universe contained 12 million galaxies that formed between 400 million years after the Big Bang and the present day.

"We compiled 20 years of astronomical observations," Peter Behroozi, assistant professor at the University of Arizona's Department of Astronomy, who led the study, said. "That gave us a lot of information about the universe – how many galaxies are there, how fast do they seem to be growing and are a lot of them close together in one part of the sky or are they randomly distributed."

The results revealed something surprising about star formation. Scientists had commonly believed that star formation was less efficient in the early universe, with the energy emitted by black holes and supernova explosions thought to stifle the birth of new stars in galaxies.

However, the recent study showed that star formation may have been more efficient in the early universe, suggesting that black holes and dying stars play a smaller role in preventing star formation.

"All previous simulations seemed to point that galaxies don't form stars so easily in the early universe," Behroozi said. "But we found the opposite, that star formation was more efficient as we went back in the early history of the universe."

In the young universe the supermassive black holes found in the centre of most galaxies emitted large amounts of energy as they fed off surrounding matter. This prevented gas from cooling down and collapsing into the dense pockets that give birth to stars. Additionally, radiation emitted by supernova explosions from dying stars would prevent the gas from cooling down.

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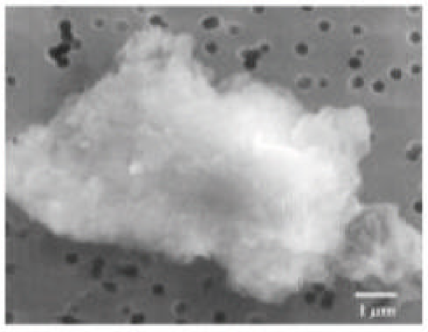
Interstellar dust has been found among Antarctic snow



© Don Brownlee, University of Washington, Seattle; Elmar Jessberger, Institut für Planetologie

Fresh interstellar dust discovered in Antarctica

Words by **Charles Q. Choi**

By examining Antarctic snow researchers have discovered, for the first time, interstellar dust that recently fell to Earth, a new study finds.

These findings may shed light on the mysterious interstellar clouds the Solar System flies through regularly, scientists said. Tons of extraterrestrial dust – created by passing comets, asteroid collisions and exploding stars – falls on Earth daily. But scientists may not find it until long after it has fallen, and so lack details about the Solar System's recent interactions with its surroundings. By contrast this new study analyses relatively fresh interstellar dust, and the findings may reveal insight into mysterious interstellar clouds and their relationship with our Solar System.

"Scientists might be able to use our results to figure out how the solar neighbourhood was shaped," study lead author Dominik Knoll, an experimental nuclear physicist at the Australian National University in Canberra, told **Space.com**. "We know something about distant galaxies and stars and a lot about our Solar System, but the nearby surroundings of our Solar [neighbourhood] need more investigation."

Future examination of dust in older snow and ice could shed light on the origins and structure of nearby interstellar clouds and the history of their interactions with the Solar System, the researchers said.

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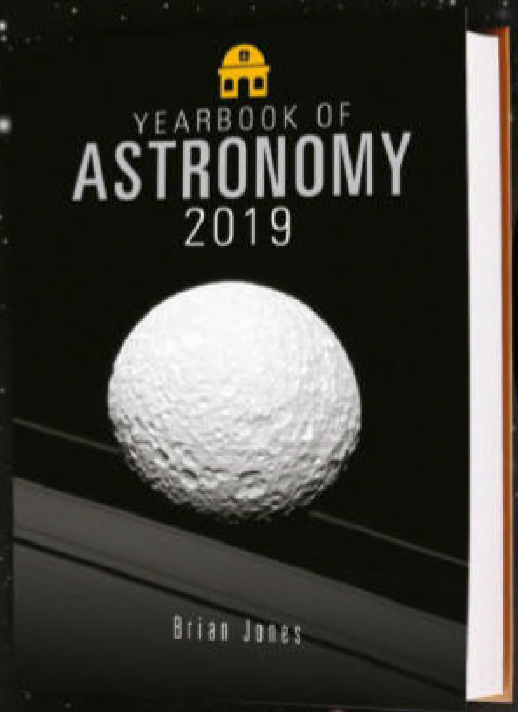

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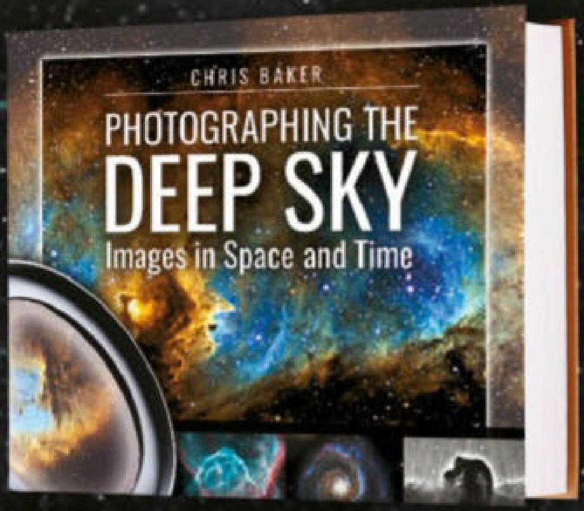

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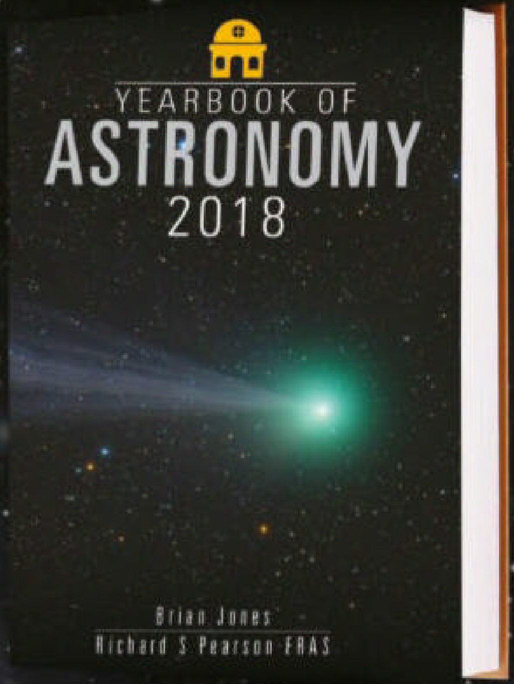

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NEW UNIVERSE REVEAL

THE BIG BANG

WAS IT REALLY THE BEGINNING?

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What happened before the birth of our universe, could soon be revealed by new research and NASA missions

Reported by Andrew May

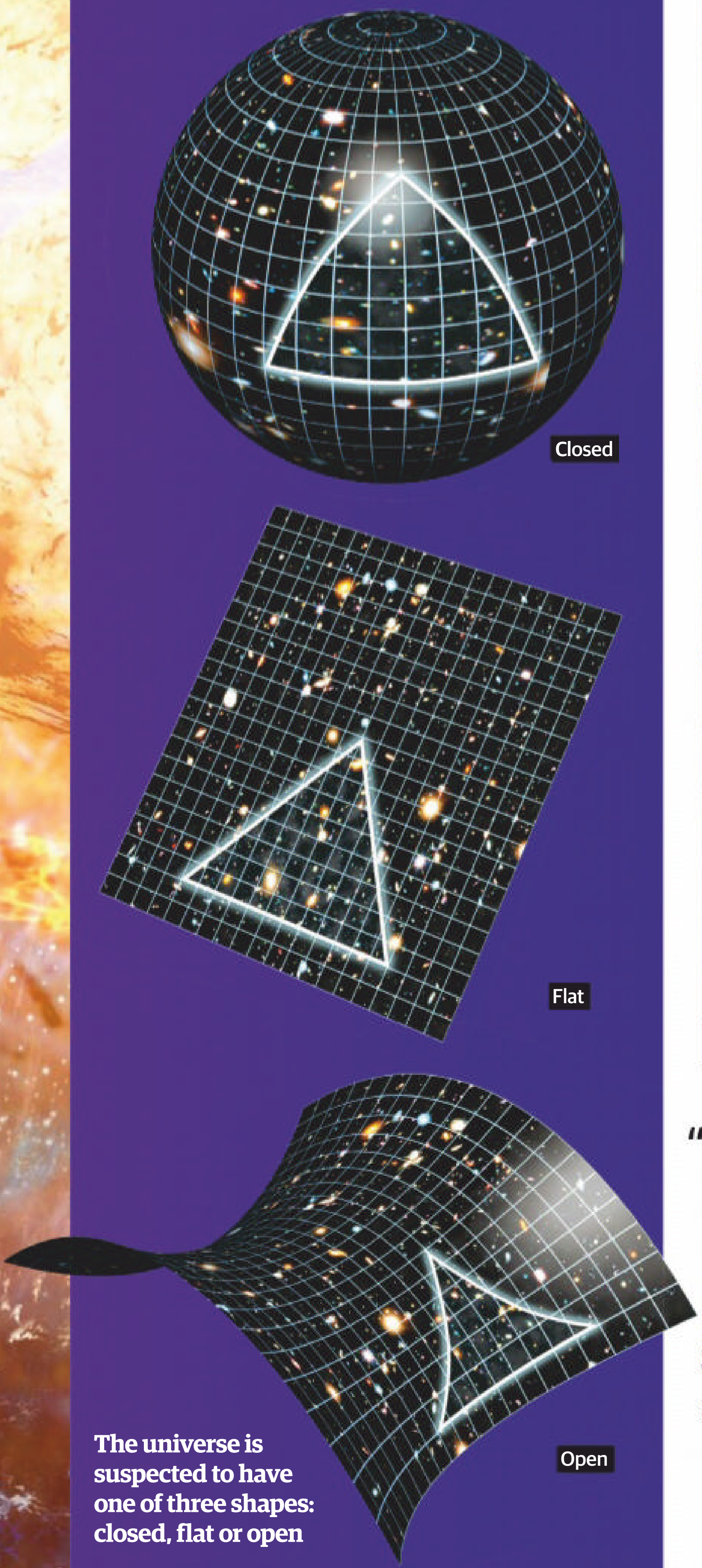
Our universe had its origin in the Big Bang, approximately 13.8 billion years ago. All the matter we now see spread out over millions of light years was concentrated into a tiny, unimaginably dense point, smaller than the smallest subatomic particle. From that minuscule beginning it rapidly expanded in size, eventually forming the stars and galaxies we see today.

This picture will be familiar enough to anyone who keeps up with modern science. But it begs the question: what happened before that? Was the Big Bang really the beginning of everything, or just the start of the current phase in the life of the universe? If there were previous phases, what were they like? As reasonable as these questions sound, they're incredibly difficult to answer because they push science to its absolute limits, both observationally and theoretically, and different scientists give very different answers. The problem is there's no consensus as to what happened at the moment of the Big Bang.

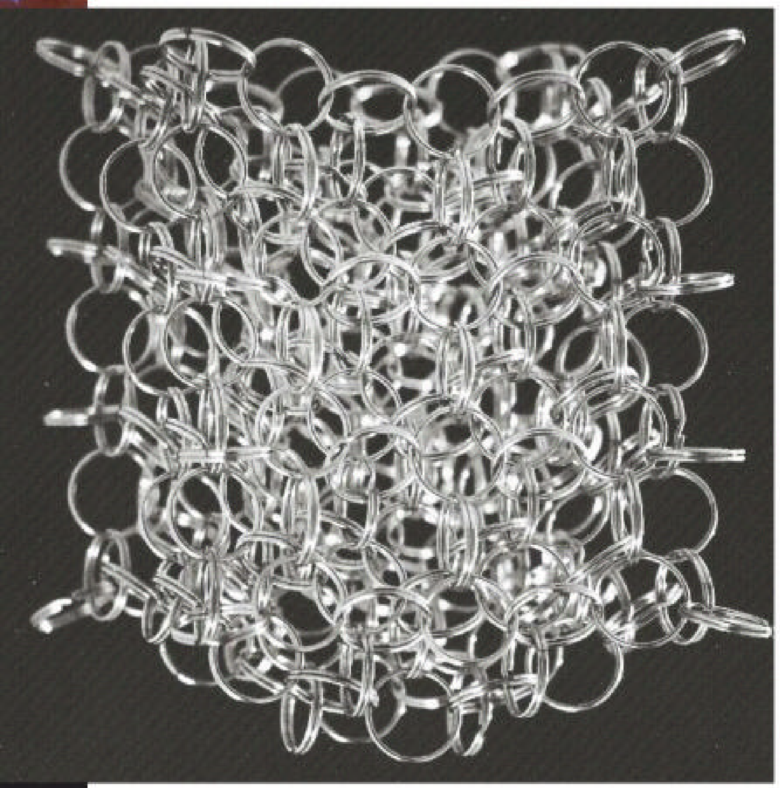
There's agreement on many points, though – such as the notion that the entire visible universe was originally compressed into a superdense 'primeval atom'. This picture originated with the Belgian astronomer-priest Georges Lemaître in the 1920s. As acceptable as it's become today, it was controversial when he first proposed it. Most scientists rebelled against the idea of a finite moment of 'creation' – and it didn't help that Lemaître belonged to a religion that held that view as an article of faith. In 1927 British astronomer Arthur Eddington wrote: "As a scientist, I simply do not believe that the present order of things started off with a bang."

Nevertheless, evidence steadily mounted up in favour of the Big Bang. First and foremost there's the observed expansion of the universe – the original stimulus for Lemaître's theory. This doesn't work like an explosion, with everything blasted out at constant speed from a central point; it's a stretching of length that scales throughout the universe. The further apart two galaxies are, the faster they move away from each other.

Lemaître explained this using Einstein's theory of general relativity, which describes the subtle interplay between mass, gravity and the shape of



The universe is suspected to have one of three shapes: closed, flat or open



“Events before the Big Bang can have no consequences, so they should not form part of a scientific model of the universe”

Stephen Hawking

space. The result was highly mathematical, but it made a number of predictions – for example about the relative abundance of chemical elements and the distribution of galaxies – which have since been confirmed by observations.

When we look at objects at greater and greater distances, the finite speed of light means we're looking further back in time. Unfortunately we can't see all the way back to the Big Bang. When the universe was younger and smaller, it was also hotter – and in its earliest stages it was filled with a glowing, super-hot plasma like the Sun. That's something we just can't see through. The furthest our instruments can penetrate is the end of this super-hot phase, about 300,000 years after the Big Bang. Technically known as 'recombination', the lingering echo of that time is seen as the cosmic microwave background – another prediction of Lemaître's theory.

What happened in the crucial period between the Big Bang and recombination? It's unobservable to us, so we have to turn to theory. The simplest approach is to extrapolate the expansion back to a state of infinite density, called a singularity. The whole space-time continuum would be compressed down to a dimensionless point, and everything science normally deals with – matter and energy, space and time, the laws of physics – would have no meaning. Those things – including time – would only come into existence at the Big Bang. According to this view it's meaningless to ask what came before the Big Bang – like asking what's north of the north pole – because there is no 'before'. That's an unsatisfying answer to our question, but it's one many scientists would give.

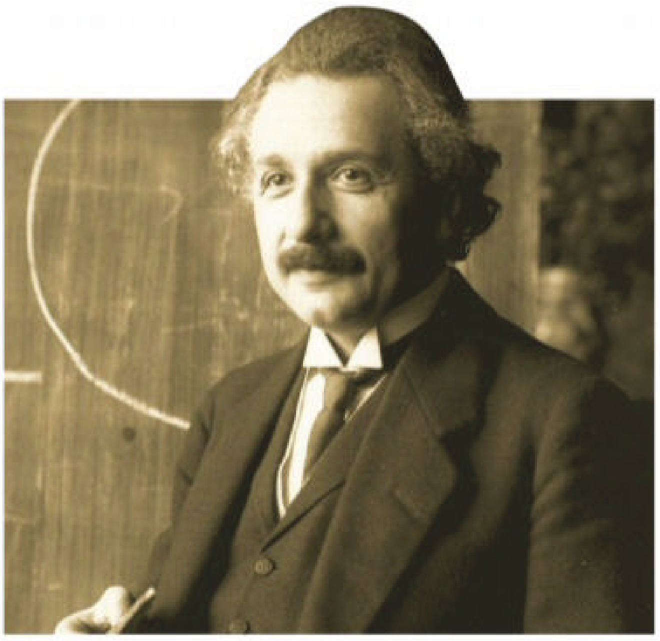
Actually, if we believe in the singularity the answer doesn't change much, even if there was a 'before'. As the laws of physics cease to exist at the moment of singularity, it's impossible for information to pass from 'before' to 'after'. For scientists who are only interested in phenomena that have observable consequences, this puts the issue of what came before out of bounds. It's a view Stephen Hawking expressed in *A Brief History of Time*: “As far as we are concerned, events before the Big Bang can have no consequences, so they should not form part of a scientific model of the universe. We should therefore cut them out of the model and say that time had a beginning at the Big Bang.”

As frustrating as this is for anyone wanting to know what happened before the Big Bang, it's an unavoidable consequence of that initial singularity which tends to crop up in any model based purely on general relativity. But is it the right theory to use?

It provides an excellent description of gravity and the large-scale structure of space-time, but we need a different type of physics - quantum theory - to explain the behaviour of matter on a subatomic scale. When we're looking at the whole of space wrapped up into a microscopically small volume at the Big Bang, we need a combination of the two - a theory of quantum gravity. That's not something that exists yet - and physicists working towards it have a whole range of views on how it would affect the Big Bang.

One possibility, which was favoured by Hawking himself, is that quantisation doesn't change the picture very much. Yes, space might wrap itself up in a way that avoids a singularity, but it might still be meaningless to talk about events before the Big Bang. "The quantum theory of gravity has opened up a new possibility in which there would be no boundary to space-time," Hawking wrote. "Maybe time and space together formed a surface that was finite in size but did not have a boundary or edge." Known as the Hartle-Hawking proposal - Hawking developed it with American physicist James Hartle - it's still a deeply unsatisfying answer to the question of what happened before the Big Bang. Other scientists, however, have come up with more interesting answers.

In the early days of the Big Bang theory, it was assumed the expansion of space would gradually slow down. After the initial impetus started the universe expanding, gravity - trying to pull it all back together - would act as a kind of brake. Given enough matter, gravity would eventually halt the expansion. After that the universe would start to contract, and continue contracting all the way back to a super-dense state. In the end it would be like replaying the Big Bang in reverse - a 'Big Crunch', as it's been called. Or maybe, as some people speculated, a 'Big Bounce' - with the whole cycle repeating over and over again. According to this view the universe might never have had a beginning - and the answer to what came before the Big Bang would be an infinite sequence of earlier universes, all expanding and contracting on an unimaginably vast timescale.



As attractive as this picture was, we now know it can't be right. In the 1990s it was discovered

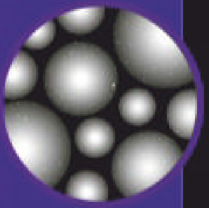
Rivals to the Big Bang

Did the universe really start with a singularity?

Steady-state theory

Maybe the universe has been expanding forever, and always looks the same because new matter is continually being created to keep the density constant.

Multiverse



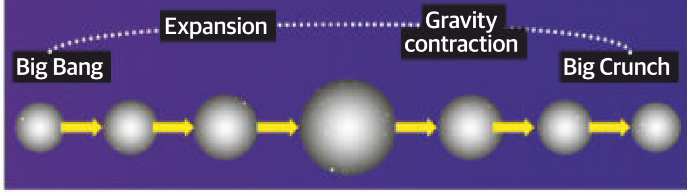
Officially known as 'eternal inflation', this scenario sees our universe as one of countless bubbles in a much vaster cosmos.

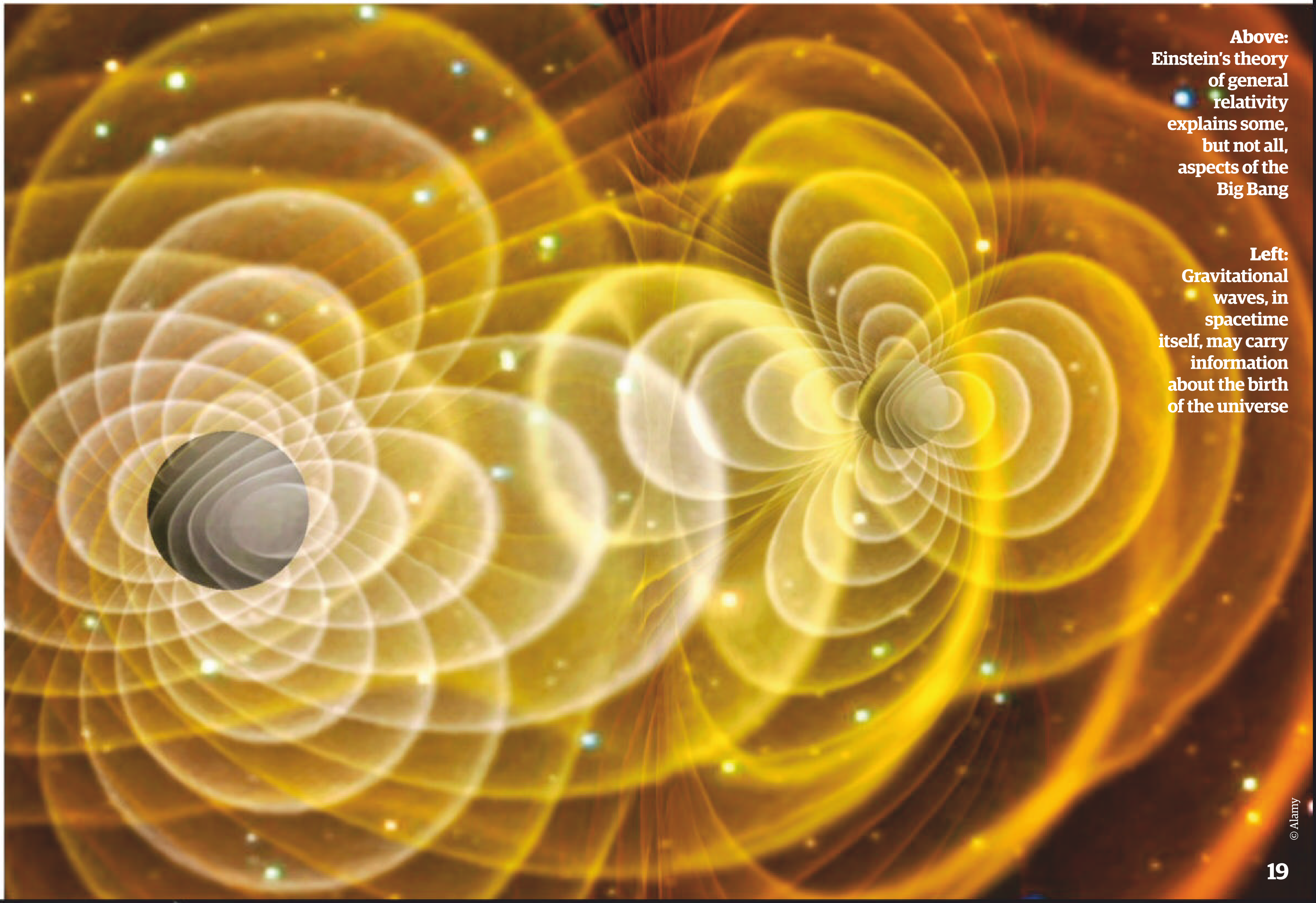
Computer simulation

Since we only know what our senses and scientific instruments tell us, maybe it's all being fed to us by a *Matrix*-style computer program.

Cyclic universe

In this view our universe is just one in a never-ending cycle of birth and death – as in the 'Big Bounce' model.





Above: Einstein's theory of general relativity explains some, but not all, aspects of the Big Bang

Left: Gravitational waves, in spacetime itself, may carry information about the birth of the universe

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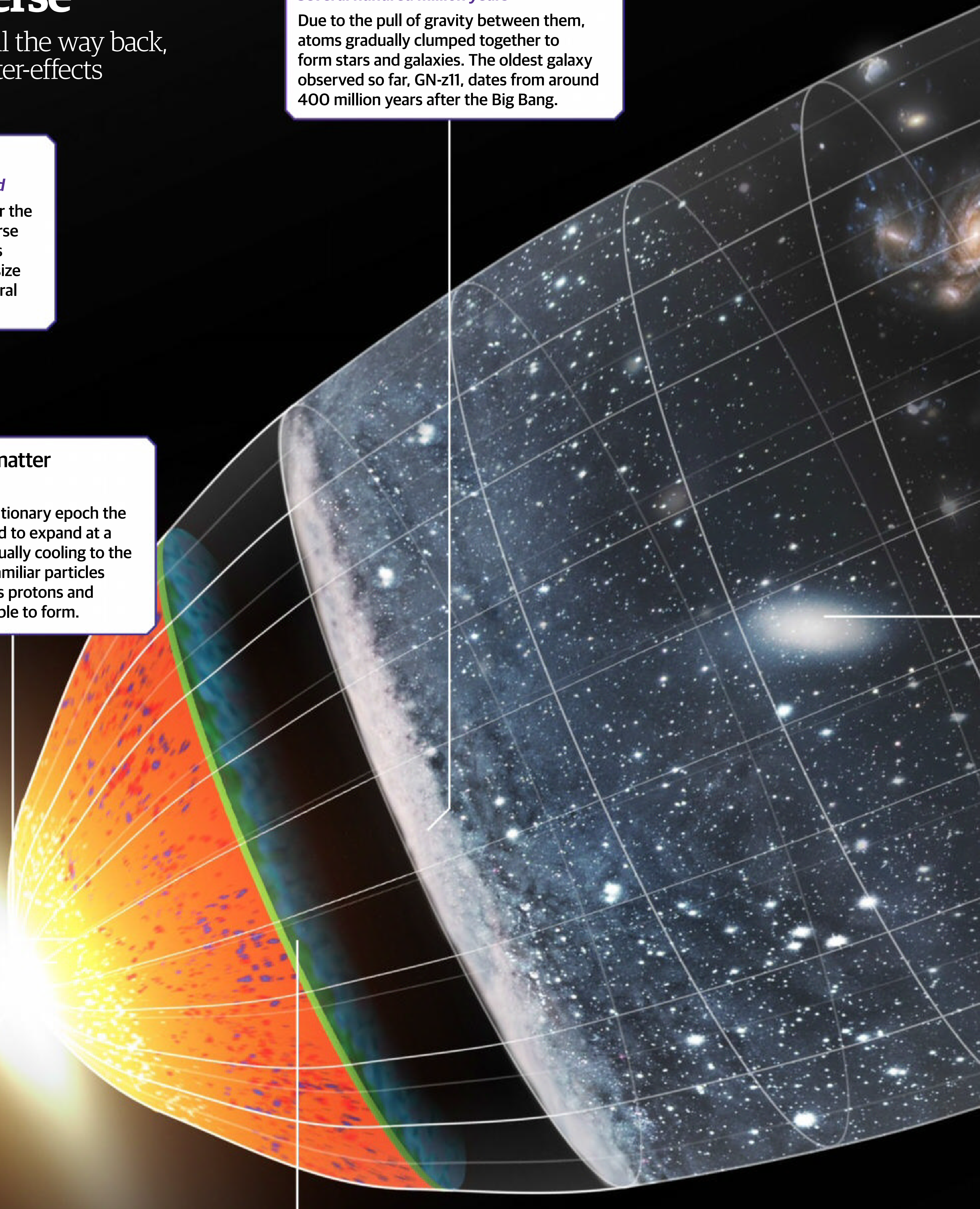
The evolution into today's universe

Although we can't go all the way back, we can examine the after-effects



1 The Big Bang

Beginning of space and time

The starting point – for our own universe, at least. Originally envisaged as a zero-dimensional singularity, modern theories suggest that's not possible. Even so, the whole of space was wrapped up into an unimaginably tiny volume.

2 Rapid inflation

The first decillionth of a second

A tiny fraction of a second after the Big Bang, the expanding universe put on a huge spurt – known as inflation – which increased its size from a subatomic scale to several light years.

3 Creation of matter

After one second

Following the inflationary epoch the universe continued to expand at a slower rate, eventually cooling to the point where the familiar particles of matter – such as protons and neutrons – were able to form.

4 The Epoch of Recombination

Between 300,000 and 400,000 years

Up to this point, the universe was so hot that matter could only exist as an ionised plasma. Then, at so-called recombination, particles combined into atoms for the first time.

5 The first galaxies

Several hundred million years

Due to the pull of gravity between them, atoms gradually clumped together to form stars and galaxies. The oldest galaxy observed so far, GN-z11, dates from around 400 million years after the Big Bang.

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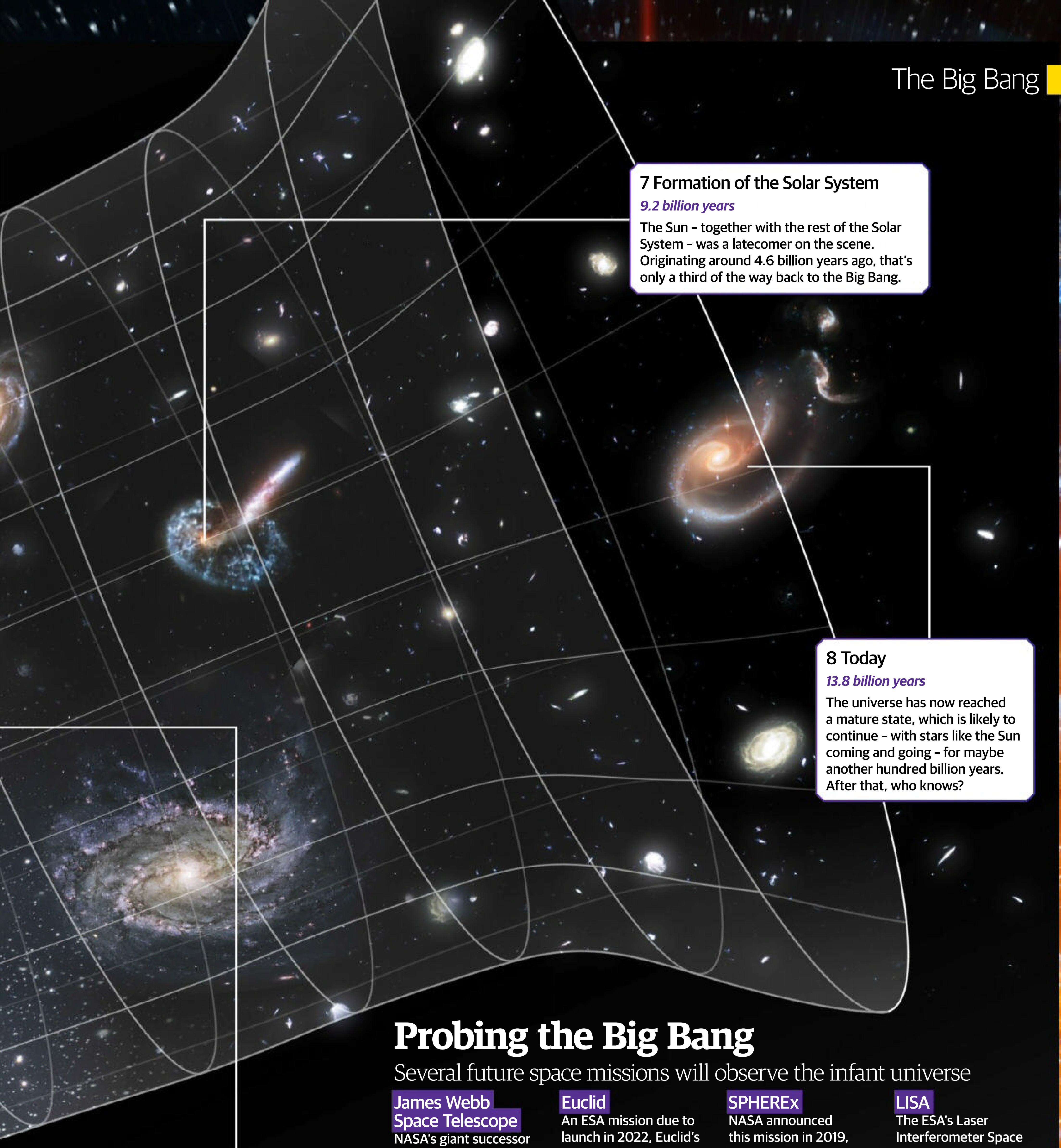


6 Expansion starts to accelerate

Around 8.5 billion years

Ever since the early inflationary epoch, the universe had been expanding at a steady rate. Then it started to speed up – an unexpected phenomenon that's been attributed to a mysterious form of 'dark energy'.

7 Formation of the Solar System

9.2 billion years

The Sun – together with the rest of the Solar System – was a latecomer on the scene. Originating around 4.6 billion years ago, that's only a third of the way back to the Big Bang.

8 Today

13.8 billion years

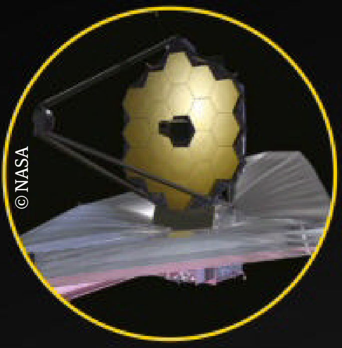
The universe has now reached a mature state, which is likely to continue – with stars like the Sun coming and going – for maybe another hundred billion years. After that, who knows?

Probing the Big Bang

Several future space missions will observe the infant universe

James Webb Space Telescope

NASA's giant successor to Hubble, due for launch in 2021. This will search for infrared light from the first generation of galaxies after the Big Bang.



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Euclid

An ESA mission due to launch in 2022, Euclid's primary goal is to probe the nature of dark energy by accurately measuring the accelerated expansion of the universe.

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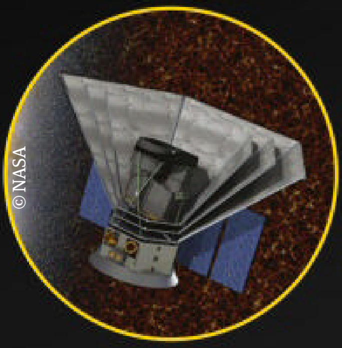
SPHEREx

NASA announced this mission in 2019, saying it would "deliver an unprecedented galactic map containing fingerprints from the first moments in the universe's history".



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LISA

The ESA's Laser Interferometer Space Antenna should be capable of detecting gravitational waves generated during the Big Bang – or even from a previous universe.

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Q&A Big Bang

There are some pretty mind-bending aspects to the Big Bang - here are some of them

Was the Big Bang a huge explosion?

No – space is expanding. If galaxy A moves away from us at speed v, then another galaxy B in the same direction, twice as distant, moves at 2v. Galaxy A sees both B and ourselves moving at speed v. It's not a constant-speed 'explosion', but a stretching of length scales.

Where did the Big Bang happen?

It happened everywhere in the universe! The fact the universe was compressed down to a tiny point makes no difference – it still filled the whole of space as it existed at that time. The Big Bang wasn't an explosion from a point into space, it's an expansion of space itself.

Can the universe expand faster than light?

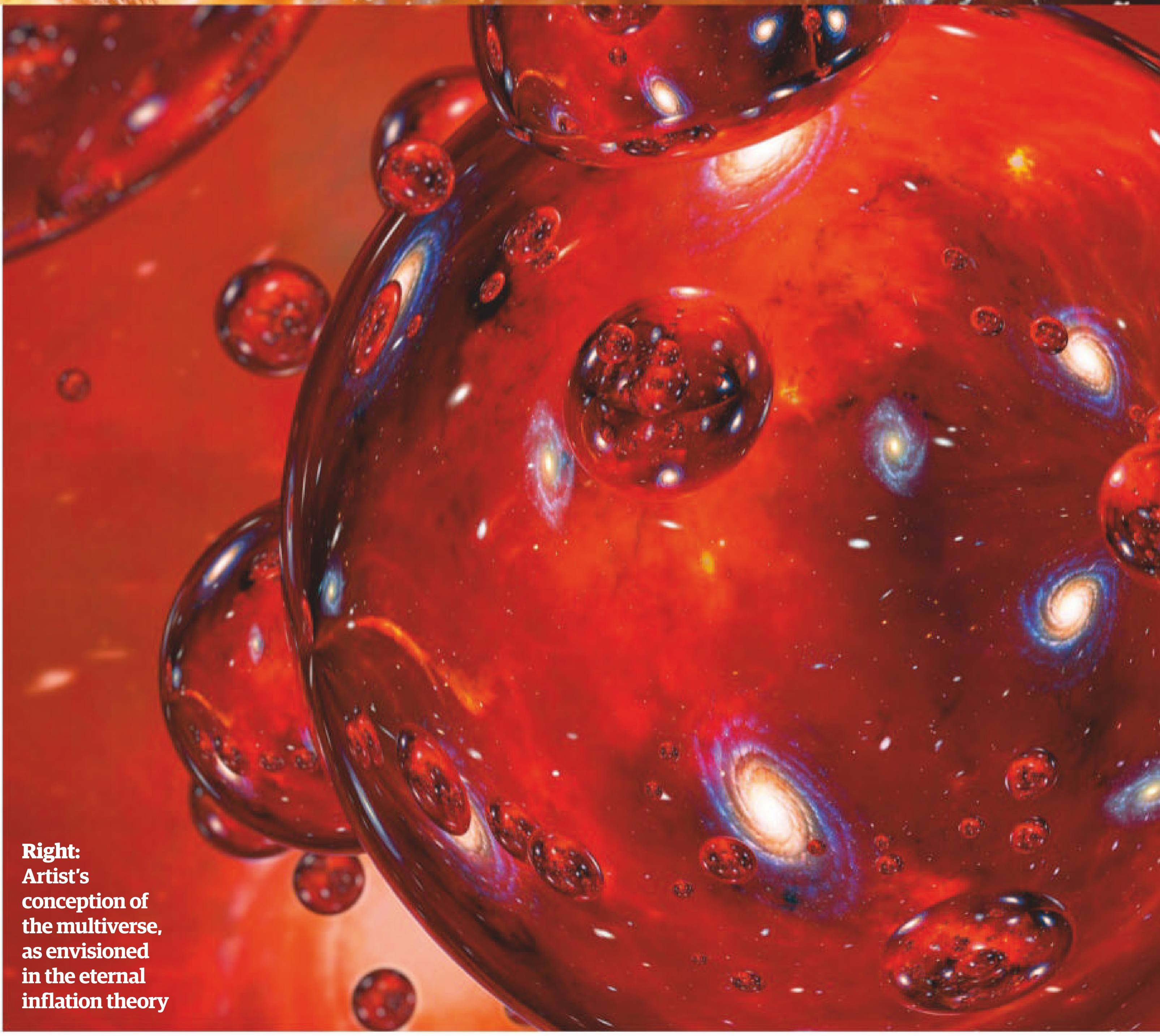
Yes – and it did just that during the inflationary period immediately after the Big Bang. It's impossible for objects to move through space faster than light, but the Big Bang doesn't relate to moving objects, but to the stretching of space itself. And space follows its own rules.

Are the galaxies themselves expanding?

No, because they're held together by gravity. In fact, many galaxies exist in clusters which are also gravitationally bound, and hence constant in size rather than expanding. It's only on larger scales, between objects that aren't tied together by gravity, that we see the universe expanding.

Did the Big Bang make a sound?

No. Sound is a vibrational wave in material objects – solid, liquid or gas – and such objects didn't exist at the Big Bang. Sound only became possible after the first particles formed. We see traces of these earliest sounds in the form of 'baryon acoustic oscillations' in the cosmic microwave background.



Right: Artist's conception of the multiverse, as envisioned in the eternal inflation theory

© Getty

that far from slowing down, the expansion of space is speeding up. It seems the universe is filled with some mysterious 'dark energy' that counteracts gravity and causes the expansion to get faster rather than slower. Even in the presence of dark energy, however, a cyclic universe may still be possible.

Imagine a universe that, instead of recontracting, expands ever more rapidly thanks to dark energy. Space will get colder, stars will flicker out and galaxies will drift further and further apart. Eventually nothing will be left but a vast, diffuse sea of emptiness. This may sound like the exact opposite of the Big Bang, but it's a good match to the starting conditions of the universe according to a different theory, proposed by Paul Steinhardt and Neil Turok.

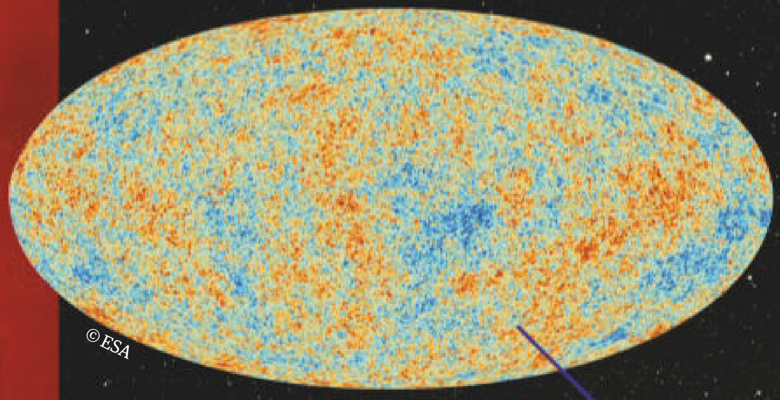
Its official name is the ekpyrotic model, but Michio Kaku refers to it more evocatively as the 'Big Splat'. It's formulated in terms of a controversial variant of quantum gravity called M-theory, which sees the universe as a three-dimensional membrane, or 'brane', inside a higher dimensional space. As Kaku says: "Two flat, homogeneous and parallel branes … start as empty, cold universes, but gravity gradually pulls them together. They eventually collide, and the vast kinetic energy of the collision is converted into the matter and radiation making up our universe." Like its predecessor the Big Bounce, the Big Splat model results - according to its originators - in a universe that runs through an endless sequence of birth, death and rebirth. "When you ask why the universe is the way it is," Turok says, "well, it's because it has to be that way in order to repeat the next time around."

M-theory isn't the only approach to quantum gravity. Another - pioneered by, among others, Abhay Ashtekar of Penn State University - is loop quantum gravity (LQG). While M-theory seeks to extend quantum theory to incorporate Einstein-style space-time, LQG attacks the problem from the opposite angle, attempting to quantise general relativity. It has the advantage of automatically banishing singularities because it considers space itself to be quantised into incredibly tiny loops, hence the name, so it's no longer possible to have an infinitely small point. Where does that leave the Big Bang? The answer, once again, is a picture of eternal recurrence. "Using quantum modifications of Einstein's cosmological equations, we have shown

> "Using quantum modifications of Einstein's equations, we have shown that in place of a classical Big Bang there is in fact a quantum bounce" **Abhay Ashtekar**

Evidence for and against the Big Bang

Observations indicate the Big Bang theory is correct – but is it correct enough?



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Accelerating expansion

We know the universe is expanding ever more rapidly – the red curve – but the original Big Bang only allowed the other curves. Something else – such as dark energy – must be interfering.

'Too old' supermassive black holes

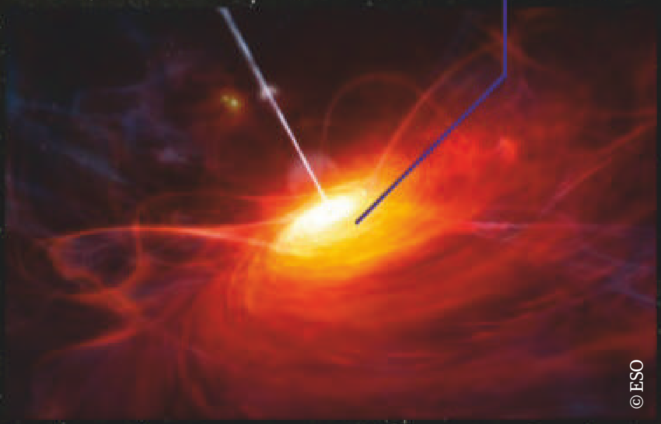
Quasar ULAS J1120+0641 dates from soon after the Big Bang, yet contains a two billion solar mass black hole. Some astronomers believe it's the relic of a previous universe.

Expansion of the universe

We know the universe is expanding today – because galaxies are moving away from each other – and if we extrapolate the expansion backwards, it implies the Big Bang must have happened.

Cosmic microwave background

The visible relic of the early universe's 'recombination' epoch – a prediction of the Big Bang theory that can't be explained by rivals such as the steady-state model.



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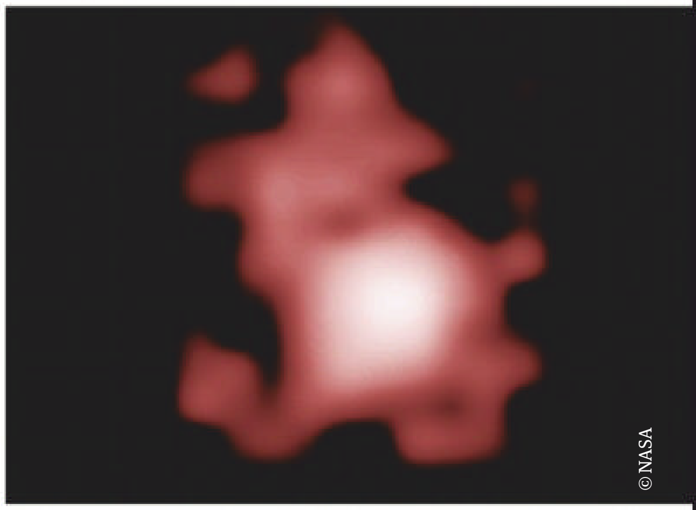
that in place of a classical Big Bang there is in fact a quantum bounce," Ashtekar says.

So far the answers we've had to the question of what came before the Big Bang fall into two categories: either 'the question is meaningless' or 'an endless cycle of previous universes'. There's a third possibility, too – that our universe is just one tiny bubble in a vast multiverse alongside countless other bubble universes stretching infinitely far into the past and future. Known as 'eternal inflation', this picture is popular with many scientists, including Britain's Astronomer Royal, Lord Rees. As he puts it: "What we've traditionally called the universe – the aftermath of 'our' Big Bang – may be just one island, just one patch of space and time, in a perhaps infinite archipelago."

So which of these views is the right one? That's a question **All About Space** put to Brian Clegg, author of *Before the Big Bang*. He is highly sceptical about the concept of eternal inflation, for a start. "It builds speculation on speculation," he says. "I'm more comfortable with theories where the universe starts with a bounce. Of these, I have a preference for approaches based on loop quantum gravity, with its potential for a not-quite-a-singularity bounce. While something like the ekpyrotic theory based on M-theory is fun, I'm not convinced that M-theory is really science at all."

But a lot more work will be needed before we can really be sure. Clegg specifically highlights we require "better observational data to support or weed out things like inflation – including potentially primordial gravitational waves – and theoretically a more advanced LQG or replacement for it."

While present-day technology can detect gravitational waves from events like black hole mergers, the 'primordial waves' mentioned by Clegg have much longer wavelengths, and will have to wait for a future generation of space-based detectors. When that day comes there's an even more intriguing possibility, suggested by Brazilian physicist Juliano César Silva Neves. Another fan of bounce models, Neves believes that "black holes or gravitational waves from the previous phase" – before the Big Bang, in other words – "may be present today", and hence potentially detectable by future technology, so we'll have to wait and see.



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Above right: This fuzzy image shows Hubble's view of the most distant known galaxy, GN-z11

Right: An artist's impression of the birth of the universe – an exceedingly hot era during the history of space and time

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INTERVIEW BIO

Margaret Hamilton

Margaret Hamilton was a computer scientist and software engineer during the Apollo era. She joined the Charles Stark Draper Laboratory – now known as Draper – at the Massachusetts Institute of Technology (MIT) in 1964. From there she helped develop the on-board flight software as was given the role of lead programmer on the Apollo Guidance Computer (AGC). The AGC was a pivotal part of the Apollo spacecraft, and the mission simply wouldn't have been possible without the diligent work of Hamilton. This earned her Presidential Medal of Freedom in 2016, awarded by Barack Obama.

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THE SOFTWARE GENIUS BEHIND THE MOON LANDINGS

Margaret Hamilton reveals the inside story of the Apollo program and how sacrifice, hard work and constant questioning led to the completion of arguably humankind's greatest ever adventure

Interviewed by Lee Cavendish

What was a day in the life of a NASA computer scientist like during the 1960s?

On the unmanned missions I began writing software mostly in the system software area. We had a lot to do with error detection recovery. My first piece of programming, which we now refer to as 'software engineering computer science', or some combination there of, had to do with error detection recovery, because they were worried about unmanned mission aborts - we needed the post-mortem software.

So they [Draper management] thought, 'We're going to give it to Margaret, because she's a beginner and it doesn't matter if she screws up because that means the mission is aborted anyway, so no big deal'. So I wrote the abort program and I called it 'Forget It', because if it didn't work, it went to post-mortem. Then wouldn't you know, the very next unmanned mission aborted, and it went to this program called 'Forget It'. That made an impact on me, even though the people on the project, the engineer guys and everything, said we would never abort because everything was going to run perfectly. That's when I learned that, when they say it's never going to happen, I shouldn't believe them, and I always said 'what if it happens'.

After the unmanned missions I worked on the systems software, which had to do with the software that affected all the people working on it. So if you made a mistake, it affected everybody with this software. After that, when the manned missions started, I took over - I was the lead - the manned software, which involved the Command Module, the Lunar Module and the systems software shared between them. The big challenge was that it had to be 'man-rated'. So now I started worrying about errors even more than I did back in the old days on the unmanned missions. What 'man-rated' meant from a software perspective was that the software system itself, with all the code, could have no errors. You couldn't have any errors, including data conflicts, timing conflicts and priority conflicts, and also included error detection and recovery in real-time when it was running.

Anyway, it had all to do with software and systems. Software interfacing with other software, software interfacing with hardware to astronaut-ware and whatever other -wares there were around to interface to!

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When you talk about the software for aborting the mission, would this have been used for the famous moment where Neil Armstrong and Buzz Aldrin were running out of fuel when they managed to land on the Moon?

That's what I worked on more than just about anything. But yes, that's a mission where I have many memories about the putting together: why it was put together, what led up to it, how it was put together, what it did and how it affected the mission.

What were the alarms going off before the landing and what were you doing when they were going off?

Well, one 'what if' I had was, what if there's an emergency during the mission and there was no way to tell the astronauts about it. The hardware could know, the software could know, but what about the astronauts? They should know if an emergency is going to happen. That was my main worry a couple of years before I put together the software. I wanted to bring up the problem to the hardware guys and the mission guys, but first they were going to say, "How are you going to solve it?"

I held a meeting with the hardware guys first and told them the problem and how I would solve it, and these were higher-ups. One of the hardware guys said, "Yeah, but there's one problem." I said, "What's that?" Then he said, "You can't talk to the astronauts unless the DSKY [Display Keyboard] is on." They said, "Let us think about it for a couple of days and we'll come back to it." They came back a couple of days later and said they were going to do it, and they were going to keep it on all the time so that the software can interface to the astronauts.

What it needed to do was, where the software was asynchronous - higher priority things could interrupt other priority things - the communication at the time was synchronous with the astronaut. If the software wanted to interrupt the astronaut it had to be an asynchronous system with the astronauts, with the two systems in parallel.

Then along came mission experts, hardware experts that said, "Yeah, we see what you're doing, but it's never been done before and it can't be done. It's one of the biggest problems with distributed processing." So I asked them what the problem would be, and they described the problem to me and I'll refer back to it, but I went home that night and I thought after I had gone through all this, I don't not dare to do this.

I came back the next day and I described the solution and they said, "Yeah, that would work." So we were running often with support from the hardware, support from the people that trained the astronauts and mission control. A big hurdle was to know that you weren't going to have the man-rated requirement compromise.

So then, back to the present in the past, when this happened just before the landing there was an emergency, and the priority displays noticed that it was one of the never-supposed-to-happen alarms that came up. In this case a 1202 and a 1201 alarm came up, and it was one of those never-supposed-to-happen alarms.

Meantime, back in the Mission Control area, prior to the mission the astronauts were in simulations practising before the landing. They were practising with Jack Garman, who was the software counterpart at Mission Control. When they were practising, Aldrin would hurry through and get to the landing, because that's what he wanted to practise. So he kept practising and noticed that if you put the rendezvous radar switch in a certain position that would help get quickly through to landing, but then what happens is if you forget to put the switch back, the 1202 and 1201 alarms would come up.

That happened a few times; sometimes it didn't happen. So they knew what caused those alarms and they were familiar with it if they saw an emergency 1202 or 1201 alarm. The astronauts recognised it and Jack Garman recognised it, as he practised with them a lot.

Now keep in mind the astronaut actually created the mistake, but it was interesting that we were warning the astronaut because he was the one that could fix that mistake, ironically.

Going on at the same time at Mission Control, the bosses were saying to Jack, "What do we do?!" And Jack noticed, "Oh, okay. It's a 1202 and a 1201. We know what to do. We take off the switch and put it back to where it belongs." And they weren't worried and depending on Jack, as he understood being a user of the software, as did Aldrin.

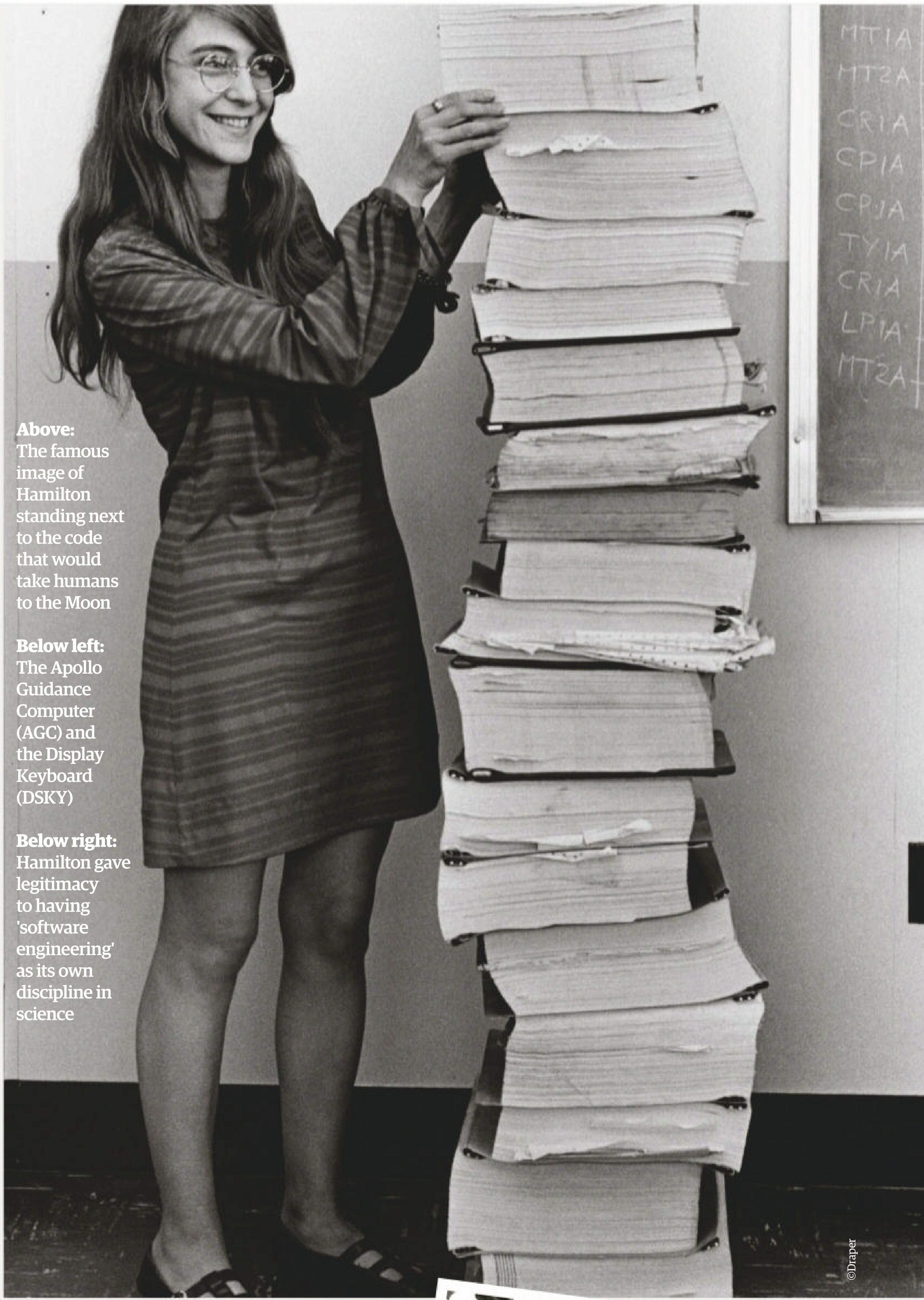
Where were you when this was unfolding?
In the SCAMA [MIT's System Control and Monitoring Arrangement] room.

What was going through your mind?
Well, I'd like to lighten it a little bit, but it was sheer panic [laughs]. I didn't know whether to be worried about the astronauts or the software!

What's the story regarding your daughter and how she found a problem in the software?
Well, Lauren is her name, and we're talking about Apollo 8. I would take her to work with me, often on nights and weekends – not during the normal hours. Well, no one back then had normal hours! But we actually simulated stuff in a digital way, but also hardware; we had the hardware just like the astronauts had.

I was practising with the hardware simulation one time when I took her to work and she wanted to play astronaut. So she went over and started playing, thinking she was doing what I did, and all of a sudden the system crashed. On her own, playing around, she got the mission started and then she started playing around again, and she was in mid-course in the mission, on the way to the Moon, and then she hit some other keys which selected the prelaunch program, which then wiped out all the navigation data mid-course.

She didn't know what she was doing. When I saw what happened I said, "Oh my god, this could



Above: The famous image of Hamilton standing next to the code that would take humans to the Moon

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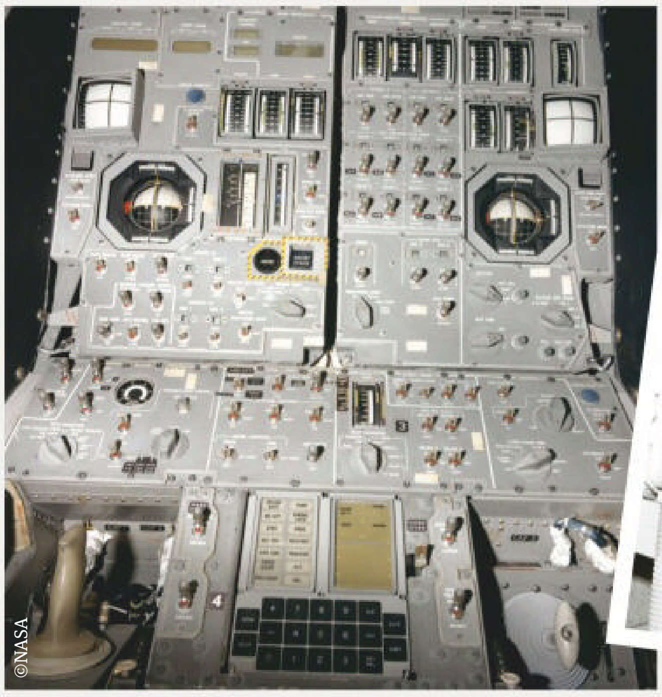
Below left: The Apollo Guidance Computer (AGC) and the Display Keyboard (DSKY)

Below right: Hamilton gave legitimacy to having 'software engineering' as its own discipline in science



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Right (clockwise): Buzz Aldrin during the Apollo 11 mission to the lunar surface

The work of Hamilton and the rest of the Draper team were instrumental in getting humans to the Moon

Jim Lovell on the Apollo 8 mission, during which he made the almost-critical 'Lauren error'

happen with the astronauts. They could do the same thing." Keeping in mind, mission phases [in the software] could not share. There was not enough room in the computer's software, so when they shared it was a big no-no and knocked out the navigation system.

I went back to the higher-ups at MIT and NASA and I said, "What if the astronauts did the same thing?" "Never would happen," they said. Just like that. "Forget it. Never would happen." So I said, "What if it happens?" "No, it won't happen. They [the astronauts] are too well trained. It's not going to happen." I said I wanted to put a change in to prevent an astronaut from doing that. They said, "No, you can't do that." So I said, "Well, can I at least put in a program note - which was a formal spec that goes with that - and say 'do not select P01 during flight.'" Which was yet another one that caused laughter among everybody, because it was funny. Why would anyone select prelaunch while they're in flight? The astronaut knows better.

Well, wouldn't you know that the very next flight, Apollo 8, [Jim] Lovell did exactly that, what we call the 'Lauren error'. And I remember being in the SCAMA room, and the guys were there and they were wondering what's going on. I remember saying it's the Lauren error. Just after the flight they said, "You can put that change in now if you want."

Was it the fact that you were so constrained in the amount of physical space you had which made it hard to put that small bit of code in?

Yes, absolutely. That had problems of its own. That's the reason why we rolled mission phases in and out, but that caused errors, and we tried to force fit stuff in there, but that again caused errors. We also had asynchronous, and then we'd have errors because things would be interrupting, and then how do you know it's going to happen safely. We had a lot of knowledge about errors, having those constraints.

How hard was it to create software that astronauts could understand and control?

That was part of it, the other part was having it man-rated and trying to make it fit. Many problems existed with that which people don't have to contend with now, but they have other problems. They have so much room; they can make all kinds of errors and make it a more complex system of errors.

But how hard was it? The priority display, that was the first time that kind of interaction had taken place, and also the first time that a distributed environment had to be set into place. At the time it wasn't hard because we didn't know any better. We just did what we thought had to be done. You just solved it because you just could not fail, not because of your management, or NASA or whatever, but because we all had the attitude we can't fail. It has to be right.

What were your initial thoughts as Neil Armstrong and Buzz Aldrin took their first steps on the Moon?

Well, I was there [in the SCAMA room] as one of the people that were required because it was going through the things it was going through. But when the 1202 and 1201 alarms came up, I knew this wasn't supposed to be happening, and I also recognised the software. My reaction was, "Why didn't it happen before this? Why now, during the first mission to land on the Moon?" But at the same time I had confidence in the software, and so I just thought it is what it is. You've just got to get through it and in fact it worked out.

When it landed it was maybe the most exciting moment of my life. Because in a sense everything came rushing through my mind, what with the background and getting to that point, it was an interesting feeling of what the software was doing, how we got there, the things we went through to get there. But all of that just came in a rush.

> "When the alarms came up, I knew this wasn't supposed to be happening, and I also recognised the software"

TROUBLE INTERNATIONAL

ON THE SPACE STATION

Next year marks two decades of continuous human occupancy of space, but things haven't always run smoothly...

Reported by James Romero

This achievement of political ambition, engineering execution and international collaboration has changed the nature of space exploration. Following the initial period of politically motivated, headline-grabbing forays into space and then to the Moon came a more settled, but no less important period of habitation.

"Because of the International Space Station, space exploration is no longer an up and down activity," says space historian Robert Pearlman, co-author of *Space Stations: The Art, Science and Reality of Working in Space*. Cited as the largest peacetime international effort in human history, in 2014 British astronaut Tim Peake was the latest to call for the ISS to receive a Nobel Peace Prize for bringing nations together.

If the station is seen as a beacon of peace and a testament to not just human ingenuity, but harmonious collaboration in pursuit of shared goals, the realities of life on board can be far more testing. As we enter a seemingly new era of human space exploration, with proposed lunar bases and crewed missions to Mars, the lessons learnt keeping the station's spacefaring residents safe, sane and secure are more vital than ever.

These lessons begin further back than the launch of the first ISS components back in 1998. This latest low-orbit residence followed on from smaller scale celestial real estate in the form of the US' Skylab and a number from the Soviet Union which culminated in Mir, operated from 1986 to 2001.

Those early forages into temporary orbital living went ahead in spite of a limited understanding of how such an alien living environment might affect the health of the crew. And while the ISS has made efforts to negate some of the adverse complications identified from those earlier missions, there is still a lot we don't know. "Part of the reason the ISS exists is to learn how the human body reacts to extended periods of time in microgravity," says Pearlman.

Today those extended periods cover between six months and a year, which is a concern when we know that such lengthy periods in orbit produce serious muscle wastage. To combat this the space station is outfitted with its own gym equipment, and the crew work out for more than two hours each day to overcome this wastage. "The astronauts who return from the ISS are not crippled in any way," explains Pearlman. "They can walk within minutes of getting out of their spacecraft."

A less well-managed physical impact of space living comes from accounts of crew members experiencing visual impairment during their missions. "We don't know exactly what causes these changes," says Michael Stenger, lead of the Cardiovascular and Vision Laboratory at the Johnson Space Center, "but we have identified possible contributing factors. These include a build-up of pressure behind the retina, possibly brought about by weightlessness-induced headward fluid shifts."

Fortunately the complications seem to correct themselves once the astronauts are back on Earth. Indeed, current mission lengths don't seem to induce long-term changes in any physical traits. This was confirmed by a recent twin study led by clinician Francine Garrett-Bakelman, which compared changes in the molecular and physiological traits of astronaut Scott Kelly with his Earth-based twin brother Mark during, and in the weeks after, Scott's latest 340 days in space.

The study concluded that the majority of Scott's biological health variables remained stable, or returned to normal soon after landing. "The biology in our bodies can manage space travel," wrote Garrett-Bakelman. "You don't come back as the green blob. You're still human. Your lungs are working. Your heart is working."

© NASA

While the ISS has made us a home in space, others lifeforms also seem to have taken a liking to these pockets of low-gravity habitability. And that could prove bad news for crews on future missions. ISS astronauts have carried out experiments to see what the microgravity environment does for the growth of bacteria. They found species behind serious ailments on Earth, such as urinary tract infections, endocarditis, salmonella and listeriosis, became even more potent.

Other uninvited microorganisms have also stowed away on the station. Samples of mould and fungal species, brought in by the astronauts themselves or perhaps by their cargo, have been observed growing, and samples have been taken for analysis. "The longer a confined manned habitat is used, some moulds and fungi can accumulate, especially in moist locations," says Petra Rettberg from the Institute of Aerospace Medicine in Cologne. "This is not that important for crew health, but might result in damage to ISS surfaces due to biofilm formation, and might disturb the functionality of instruments."

It's a reminder that in such an extreme, isolated environment, dangers can come from unexpected places. This places extra pressure on the crew when the smallest malfunction or error in judgement can create threatening situations.

While no full station evacuations or serious medical emergencies have been reported, mishaps and close shaves do occur. Mir famously suffered both a collision with another spacecraft and a fire on board that were both life-threatening, while in 2013 Italian ISS resident Luca Parmitano almost drowned on a spacewalk. The water system inside his spacesuit started to back up and fill his helmet. By the time he had made his way back to the airlock, his helmet was almost completely filled with water and he could not see. "I experienced what it's like to be a goldfish in a fishbowl from the point of view of the goldfish," he told KGO-TV upon his return to Earth.

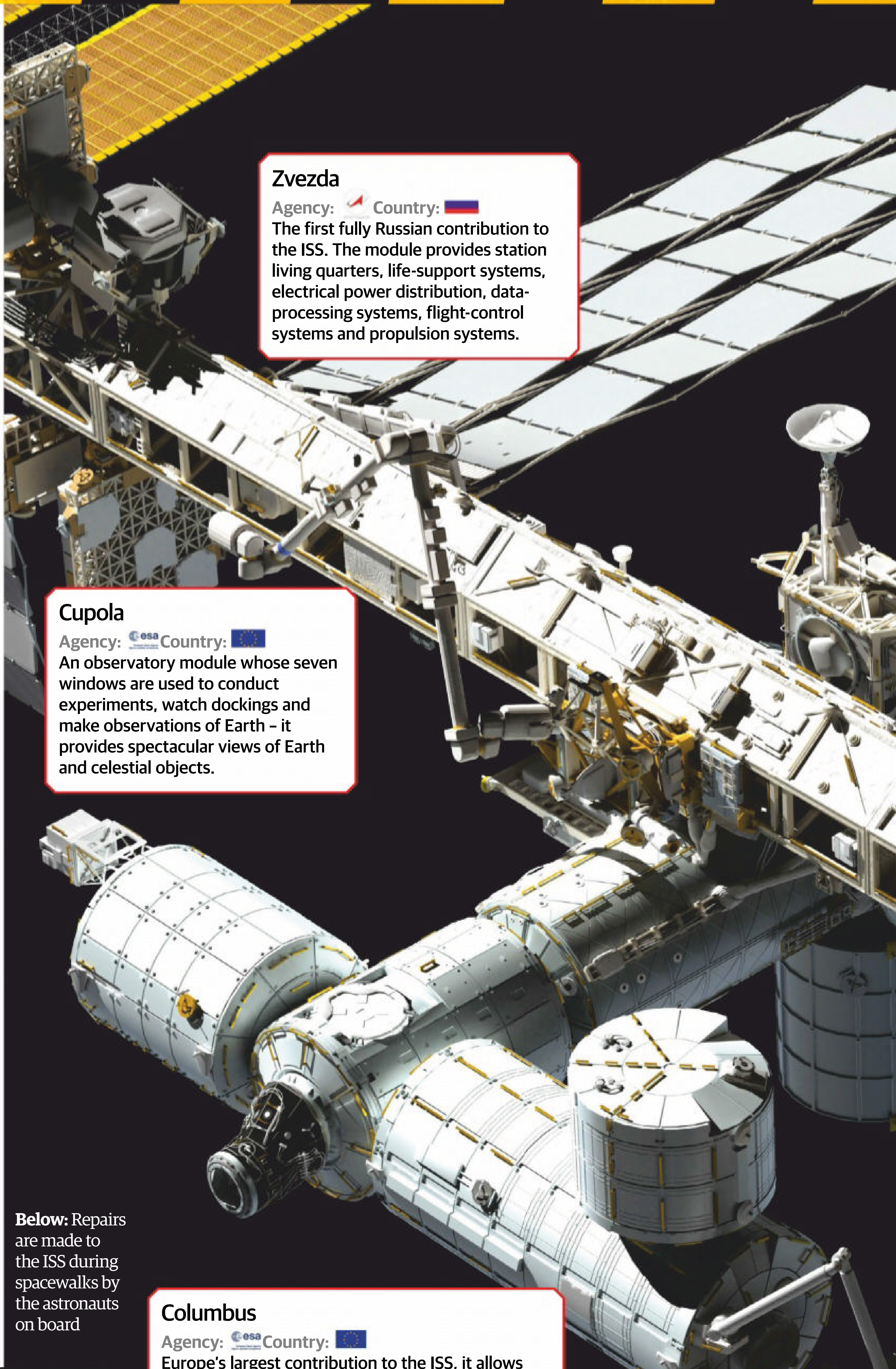
Threats to the crew on the ISS don't just come from inside the space station. "Space debris has the potential to cripple the ISS and kill the crew," Robert Frost, instructor and flight controller at NASA, told **quora.com**. "These objects are travelling around the Earth at a speed ten-times that of the average bullet from a gun. It is a highly managed risk." To combat this threat more than 23,000 objects larger than ten centimetres (four inches) across are tracked in orbit.

Below: Repairs are made to the ISS during spacewalks by the astronauts on board

© NASA

Who owns the International Space Station?

The Space Station is truly an international project, with contributions from various space agencies around the world



Zvezda

Agency: Country:

The first fully Russian contribution to the ISS. The module provides station living quarters, life-support systems, electrical power distribution, data-processing systems, flight-control systems and propulsion systems.

Cupola

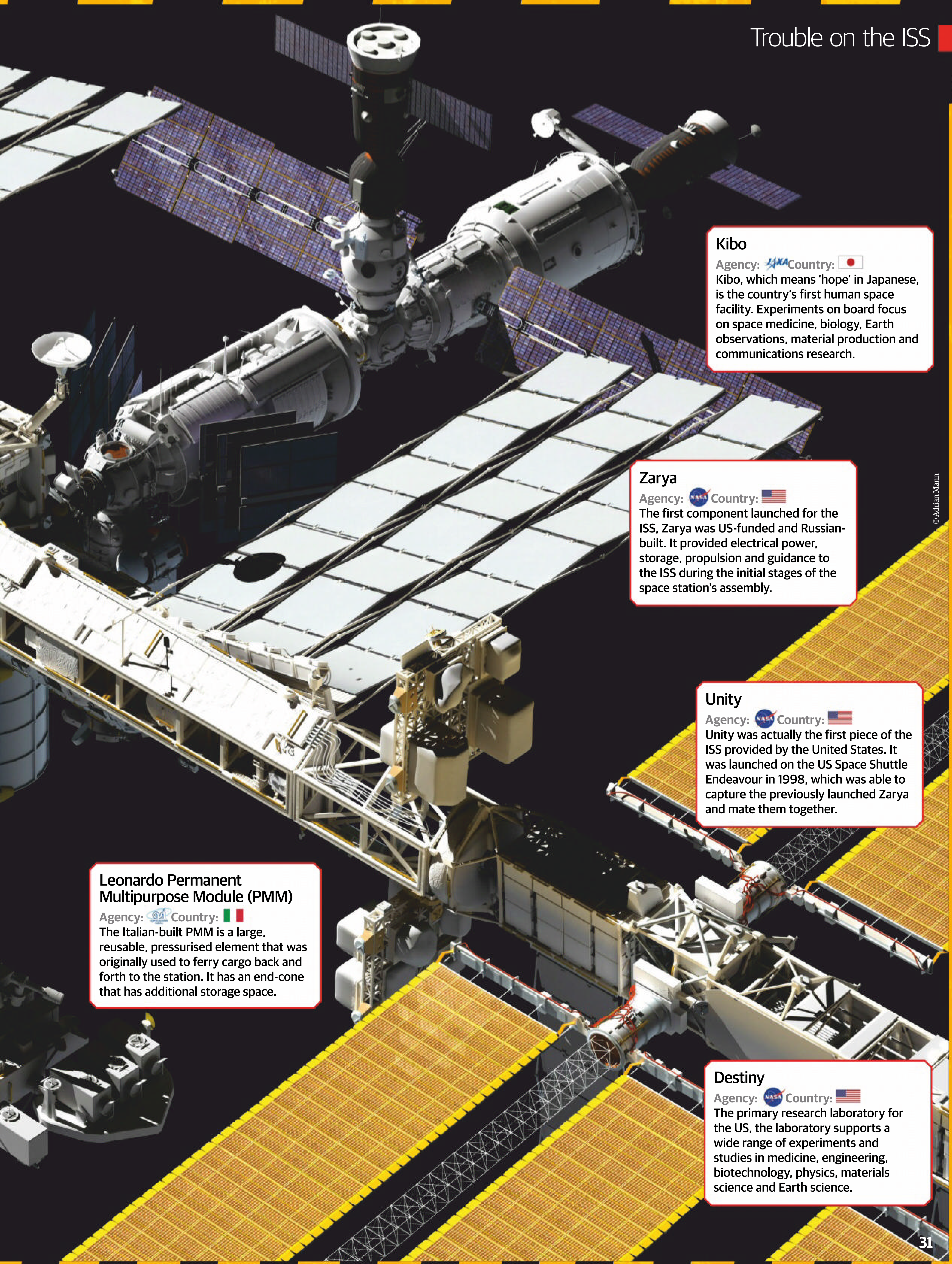
Agency: Country:

An observatory module whose seven windows are used to conduct experiments, watch dockings and make observations of Earth – it provides spectacular views of Earth and celestial objects.

Columbus

Agency: Country:

Europe's largest contribution to the ISS, it allows research to be carried out in a weightless environment, as well as outside in the vacuum of space thanks to four exterior mounting platforms.



Kibo

Agency: JAXA Country: 🇯🇵

Kibo, which means 'hope' in Japanese, is the country's first human space facility. Experiments on board focus on space medicine, biology, Earth observations, material production and communications research.

Zarya

Agency: NASA Country: 🇺🇸

The first component launched for the ISS, Zarya was US-funded and Russian-built. It provided electrical power, storage, propulsion and guidance to the ISS during the initial stages of the space station's assembly.

Unity

Agency: NASA Country: 🇺🇸

Unity was actually the first piece of the ISS provided by the United States. It was launched on the US Space Shuttle Endeavour in 1998, which was able to capture the previously launched Zarya and mate them together.

Leonardo Permanent Multipurpose Module (PMM)

Agency: asi Country: 🇮🇹

The Italian-built PMM is a large, reusable, pressurised element that was originally used to ferry cargo back and forth to the station. It has an end-cone that has additional storage space.

Destiny

Agency: NASA Country: 🇺🇸

The primary research laboratory for the US, the laboratory supports a wide range of experiments and studies in medicine, engineering, biotechnology, physics, materials science and Earth science.

© Adrian Mann

© ESA

About five per cent of those are active spacecraft and 95 per cent are spent rocket bodies, dead satellites, debris and other junk.

"If there is even a one in 10,000 chance of conjunction with an object bigger than a small grapefruit, we make plans to move," said Frost. These small debris avoidance manoeuvres take place several times a year, and are carried out by the space station's thrusters. However, this citrus fruit-scale surveillance still leaves an estimated 500,000 untracked objects out there larger than a marble, which could still cause significant damage. To prepare for the worst-case scenario of air depressurisation from a puncture there are sealable hatches between each ISS module, and the astronauts are trained to go through the process of closing those hatches, sealing off the safe areas from the damaged ones.

While the ISS has not yet been punctured from the outside, there was a recent situation where a drop in pressure was attributed to the discovery of a small hole in a Russian Soyuz capsule docked at the station. Some Russian news sources and officials speculated that the hole was the result of deliberate sabotage, though former ISS commander Alexander Gerst told BBC Radio 4 earlier this year it was caused by a botched repair job prior to launch.

This constant danger of meteorite punctures or malfunctioning components would cross the mind of even the most focused astronaut. However, the mental strain on those living above our skies for months on end generally comes from more recognisable places of isolation and distance from loved ones. Fortunately this was recognised from the outset of the ISS project, and there was a lot of talk about ways to maintain mental health, from the wall colours to agreeing on a single upwards orientation across the entire station.

Later there was recognition of the need for privacy, and so as soon as the ISS could support it, soundproof crew quarters were installed. This has been followed by a phone, weekly video calls, internet access and the inclusion of personal care packages on cargo missions, which have delivered freshly baked goods, ice cream and even sushi.

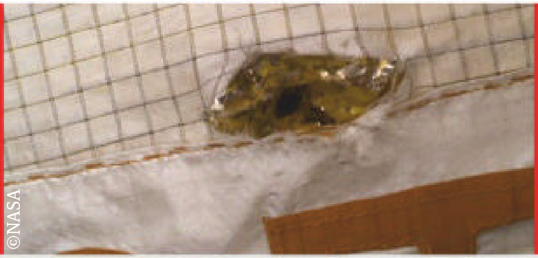
There have also been conservative efforts to build camaraderie with weekly all-crew sit-down dinners. Plus, with projectors on board, movie nights have become a popular part of the social calendar. "They've developed traditions and a culture unto

Problems on the International Space Station

Threats come from some surprising places when living in space

Micrometeorites and space debris

Space is not, as its name suggests, completely empty. Especially within low-Earth orbit, where micrometeorites and space debris such as active spacecraft, old rockets and parts from smashed-up satellites can be travelling around the Earth at ten-times the speed of the average bullet from a gun. To combat this threat, which in a worst-case scenario could see depressurisation of breathable air through a punctured hole, the space station is fitted with thrusters that can move it slightly in its orbit if an impact is anticipated.

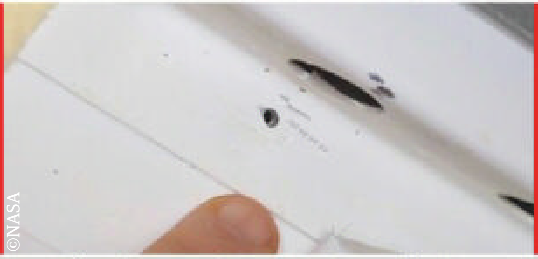


©NASA

A Russian spacewalk in 2007 discovered damage to a module's outer protective blanket caused by a micrometeoroid.

The dangers of faulty equipment

In 2013, Italian ISS resident Luca Parmitano almost drowned while on a spacewalk after a water system inside his spacesuit started to back up and fill his helmet. Another example came in 2018 when a drop in air pressure was attributed to a small hole in a Russian Soyuz capsule docked at the station. Some speculated that the hole was the result of deliberate sabotage, however, former ISS commander Alexander Gerst reported it was caused by a botched repair job prior to launch.



©NASA

In 2018 a breach opened up in the Soyuz Orbital Module's hull, allowing a very small amount of atmosphere to leak into space.

The physical strain of space living

In space you don't have gravity pulling down on you, removing some of the everyday stresses put on your skeleton and muscular system. As a result, these muscles would start to degrade if not for the astronauts daily workout regimes. Other reported health complications from space living include loss of eyesight, possibly as a result of a build-up of liquid pressure behind the retina.

©ESA

ESA astronaut Thomas Pesquet wearing the Muscle Atrophy Resistive Exercise System (MARES) in the Columbus Module.

The mental strain of space living

The dangers of space habitation, the sense of isolation and distance from loved ones puts a unique mental strain on those on board. This is made worse when astronauts experience loss during their stay. More than once an astronaut has experienced the death of a family member while on board, while the American astronaut Frank Culbertson was on the ISS on the day of the 9/11 terrorist attacks.

©NASA

Peggy Whitson and Jack Fischer make a call using one of the ISS video phones, vital to connect astronauts to loved ones.

The threat of infection

ISS astronauts have carried out experiments to see what the microgravity environment does for the growth of bacteria. They found species behind serious ailments on Earth, such as urinary tract infections, endocarditis, salmonella and listeriosis, became even more potent. Other uninvited microorganisms have also stowed away on the ISS. This is not that important for crew health, but might disturb station instruments.

©ESA

Inside the Microgravity Science Glovebox, ISS astronauts are growing bacterial colonies.

©NASA

Right:
Our planet is surrounded by thousands of chunks of space debris

Left:
Teams of astronauts take part in scientific experiments

> "We are seeing the very early stages of a new group of humanity" **Robert Pearlman**

itself. We are seeing the very early stages of a new group of humanity that we haven't seen before," says Pearlman.

This sense of community, along with the creature comforts, reminders of home and access to medical and psychological support teams on the ground are vital for when things get tough. More than once an ISS astronaut has experienced the loss of a family member while on board the space station. The inability to be with relatives at such a difficult time is a risk astronauts take when signing up to a mission, says Pearlman. "Before they fly they are asked if they want to know if someone close dies."

A similarly traumatic experience was reported by American astronaut Frank Culbertson on board the ISS on the day of the 11 September terror attacks. He has written extensively about his feelings of being off the planet and seeing smoke rising out of the former site of the World Trade Center. He later learned that a close friend, Charles Burlingame, was the pilot of the plane that struck the Pentagon.

Whatever the political situation down on the ground, astronauts and Russian cosmonauts have pointed out from the beginning that events on Earth should not impact life in orbit. Mir, which launched during the Cold War, still operated joint missions between US Space Shuttle crews and Russian cosmonauts. These were the founding principles of early space habitation and informed everything that came after. "They view themselves as a single crew," insists Pearlman. "In general, space exploration has been viewed as a way of bridging the differences between our countries."

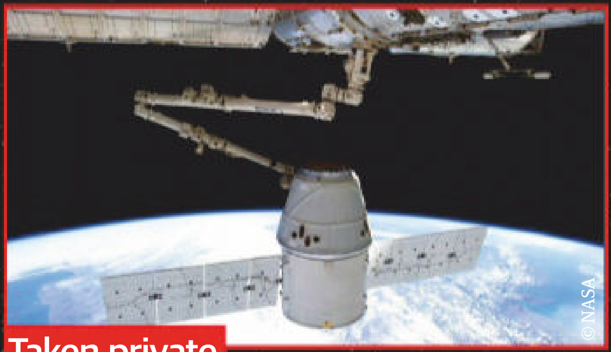
Going forward, it is this sentiment that is one of the key lessons from the space station era, and it becomes more important as the uncertain future of the ISS comes into light. Engineering studies have only given the green light for it to continue operating until 2028, and the space station programme partners have only agreed to continue operation until 2024. The US in particular seems keen to free up resources to pursue missions beyond low-Earth orbit, back to the Moon and then on to Mars.

One nation that seems set to take up the international mantle is China. It's evidence again of that one planet, one people ideal that has so far underpinned this era of space occupation. While reducing the dangers and the physical and mental toll on the crew remains a priority, the idealism continues for space habitation to be a source of hope and comfort for both future astronauts calling these stations their home, and those on the ground looking up at these unique achievements of engineering and humanity. "I think the ongoing legacy of the ISS will be the idea that we do not go this alone," says Pearlman. "That once we leave Earth, we are one people. We are human and we work together, regardless of what apparent country we originate from."

©NASA

The future of the International Space Station

The ISS might have less than a decade left, during which a lot could change



©NASA

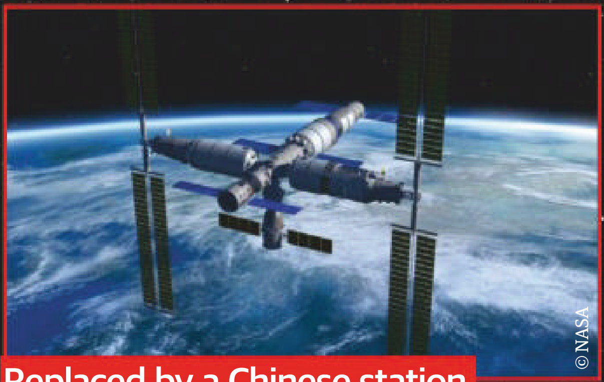
Taken private

As directed by the White House, NASA is currently assessing if and when a commercial or private entity might be able to take over operation of the US-operated segments of the ISS. Such a handover would need the agreement of the international partners, which include Russia, Canada, Japan and Europe.

©NASA

Deorbited

If a commercial or private entity cannot be identified, or if the partners do not want to continue supporting the space station beyond an agreed-upon date, then it will need to be deorbited. The station was not designed to function without a crew on board for long stretches of time. The tentative plan uses visiting vehicles and the space station's thrusters to direct the complex into a controlled re-entry, destroying it over an ocean where any surviving pieces can fall without harm.



©NASA

Replaced by a Chinese station

One nation that seems set to take up the international mantle is China, who are working towards finalising deployment of their own space station – the Chinese Large Modular Space Station – in the next few years. They've already invited other countries to send up experiments or crew members to their space station. ESA astronauts have responded by starting to take lessons in Mandarin.

IN COOPERATION WITH SPACE.com

MILLIONS OF BLACK HOLES ARE HIDING IN OUR GALAXY

Here's how astronomers plan to find them

It's time to find all the missing black holes. That's the argument advanced by a pair of Japanese astrophysicists who wrote a paper proposing a new search for millions of 'isolated black holes' (IBHs) that likely populate our galaxy. These black holes, lost in the darkness, sip matter from the interstellar medium – the dust and other stuff floating between stars. But that process is inefficient, and a great deal of the matter gets expelled into space at high speeds.

As that outflow interacts with the surrounding environment, the researchers wrote, it should produce radio waves that human radio telescopes can detect. And if astronomers can sift out those waves from all the noise that's in the rest of the galaxy, they might be able to spot these unseen black holes. "A naive way to observe IBHs is through their X-ray emission", the researchers wrote in their paper, which has not yet been formally peer reviewed, which they made available 1 July.

As black holes suck the matter from space, that matter at its fringes accelerates and forms what's known as an accretion disc. The matter in that disc rubs against itself as it spins towards the event horizon – a black hole's point of no return – spitting out X-rays in the process. But isolated black holes, which are small compared to supermassive black holes, don't emit a great deal of X-rays this way. There simply isn't enough matter or energy in their accretion discs to create large X-ray signatures. Past searches for IBHs using X-rays have failed to produce conclusive results.

"These outflows can possibly make the IBHs detectable in other wavelengths," the researchers, Daichi Tsuna of the University of Tokyo and Norita Kawanaka of Kyoto University, wrote in their paper. "The outflows can interact with the surrounding matter and create strong collisionless shocks at the interface. These shocks can amplify magnetic fields and accelerate electrons, and these electrons emit synchrotron radiation in the radio wavelength." In other words, the outflow sliding through the interstellar medium should get electrons moving at speeds that produce radio waves.

"There's a handful of objects that astronomers suspect might be isolated black holes"

Above: Excited electrons may be able to be detected by radio telescopes on Earth

© Marshmallow Laser Feast

"Interesting paper", said Simon Portegies Zwart, an astrophysicist at Leiden University in the Netherlands. Portegies Zwart has also studied the question of IBHs, also known as intermediate-mass black holes (IMBHs). "It would be a great way to find IMBHs," Portegies Zwart explains. "I think that with LOFAR [the Low-Frequency Array in the Netherlands] such research should already be possible, but the sensitivity may pose a problem".

IBHs are thought of as a 'missing link' between the two types of black holes astronomers can detect: stellar-mass black holes that can be two to possibly 100-times the size of our Sun, and supermassive black holes, the gargantuan beasts that live at the cores of galaxies and are hundreds of thousands of times the size of our Sun.

Stellar-mass black holes are occasionally detectable in binary systems with regular stars because the binary systems can produce gravitational waves and companion stars can provide fuel for large X-ray bursts. And supermassive black holes have accretion discs that emit so much energy that astronomers can detect and even photograph them.

But IBHs, in the midrange between those two other types, are far more difficult to detect. There are a handful of objects in space that astronomers suspect might be IBHs, but those results are uncertain. But past research, including a 2017 paper in the journal *Monthly Notices of the Royal Astronomical Society*, which Portegies Zwart co-authored, suggests millions of them could be hiding out there.

MYSTERIES OF THE UNIVERSE

WHAT'S UP WITH NEPTUNE?

Although the ice giant is further away than Uranus, their surface temperatures are remarkably similar. How could this be, and does it explain the planet's fierce winds?

Reported by David Crookes

Illustration © Tobias Roetsch

Neptune by numbers

164.8

Number of Earth years taken for Neptune to orbit the Sun.

30 Neptune is 30-times more distant from the Sun than Earth.

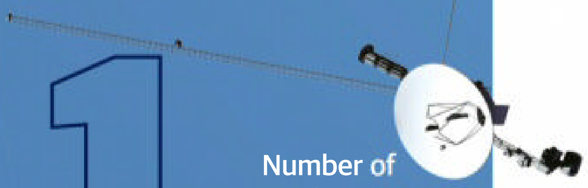
18

Hours taken to complete a single rotation.

17 Neptune is 17-times the mass of Earth, with Uranus about 14.5.

1846

The year Neptune was observed by Johann Galle, with Triton discovered shortly after.



1 Number of spacecraft – Voyager 2 – to have flown by Neptune.

19,566

Neptune's mean orbital velocity in kilometres per hour.

28.3

Degrees of equatorial inclination for Neptune, compared to 97.8 degrees retrograde rotation for Uranus.

24,622

Neptune's equatorial radius in kilometres.

62,525,703,987,421

Neptune's volume in km³.

When Voyager 2 reached Neptune in 1989, just 12 years after setting off on its historic journey through the Solar System, it discovered six new moons, took the first images of the planet's rings and noted a particularly violent storm.

This was something of a surprise. In the southern hemisphere there was a swirling, counter-clockwise wind of up to 2,414 kilometres (1,500 miles) per hour - the strongest ever recorded in the Solar System. Astronomers called it the Great Dark Spot, and while it had gone by the time the Hubble Space Telescope looked at the planet five years later, they were keen to learn why the winds were so extreme.

They were also perplexed by another issue: Voyager 2 revealed that Neptune is warmer than Uranus, despite being further from the Sun. As Professor Brian Cox discussed in his BBC documentary, *The Planets*: "The source of this extra heat remains a mystery." But does that mean we have a double-puzzle on our hands, and can one mystery help to explain the other in some way?

Before we begin to address the two issues at hand, we must first look at what is actually meant by 'warmer'. Since Neptune is a gas giant, we cannot test the globally average temperature at ground level in the way that we could on Earth's solid surface. Instead, with Neptune's core likely to be small, temperature measurements must be taken at an altitude. Trouble is, which one?

"We can only measure temperatures in the outermost layers," explains Dr Michael Wong, a planetary scientist at the University of California, Berkeley. In doing so we find that Neptune isn't actually hotter than Uranus in real terms - they're essentially at the same temperature. But since Neptune receives less solar illumination because it's further from the Sun, this shouldn't be the case.

What this similarity in temperature suggests is that Neptune is warmer in terms of how much heat it emits in comparison to the amount of heat it absorbs from the Sun. "Voyager's measurements show Neptune emits more than twice as much heat as it absorbs from the Sun, while Uranus does not," says Dr Anthony D. Del Genio of the NASA Goddard Institute for Space Studies. And this is where things become rather intriguing.

That's because Neptune is not unusual in this case. "Jupiter and Saturn also emit almost twice as much heat as they absorb, but Uranus does not," Del Genio continues. As such, he concludes, "Uranus is the oddball" and, indeed, that would appear to be the reality here.

"The progression of temperature as you go further away from the Sun shows Jupiter to be the warmest of the gas giants, Saturn next, then Neptune. Uranus is the one that is out of place," he tells us. "Yet that unusual result is associated with the fact that Uranus does not have a significant internal heat source." In other words, Neptune is finding a way to warm itself up to the level of Uranus while Uranus is unable to generate any extra heat other than that gleaned from the Sun.

But just what is an internal heat source? Well, in simple terms it is heat left over from the birth of the Solar System when these planets were formed. The heat contracts out of the primitive solar nebula - an effect known as the Kelvin-Helmholtz contraction.

"The extra heat source on Neptune [and Jupiter and Saturn] is largely due to gravitational contraction," says Joshua Tollefson, also of the University of California, Berkeley. "As the planet slowly gravitationally contracts, the material falling inward changes its potential energy into thermal energy, which is then released upwards out of the planet."

Yet there is no clear reason why Uranus does not have much of an internal heat source - or indeed any at all. "Something must have stunted

Below: Triton is the largest of Neptune's moons, and was the first discovered

© NASA

Many moons

Neptune has 14 moons, six of which were discovered by Voyager 2. The largest, Triton, is composed of frozen nitrogen ice over a core of rock and metal, and it's the coldest known object in the Solar System.

Inside Neptune

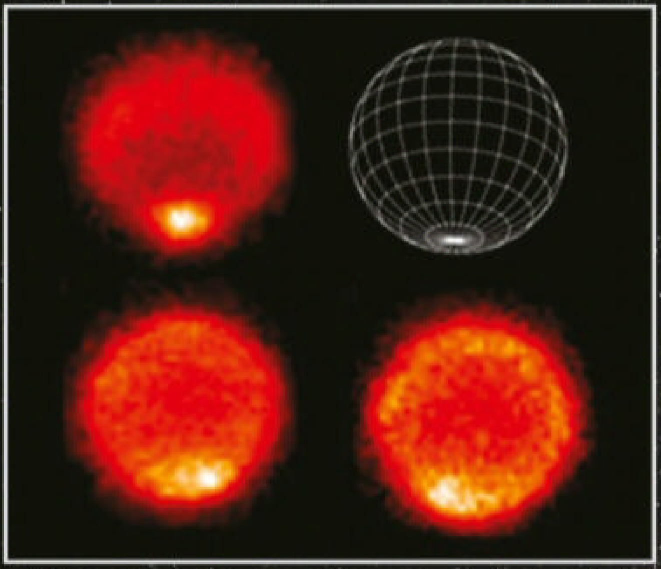
How the distant planet is structured, and what makes it rather unique

Gassy atmosphere

What we see when we view Neptune is a gas layer – an atmosphere of 80 per cent molecular hydrogen, 19 per cent atomic helium and a percentage of methane and trace gases.

Heat giver

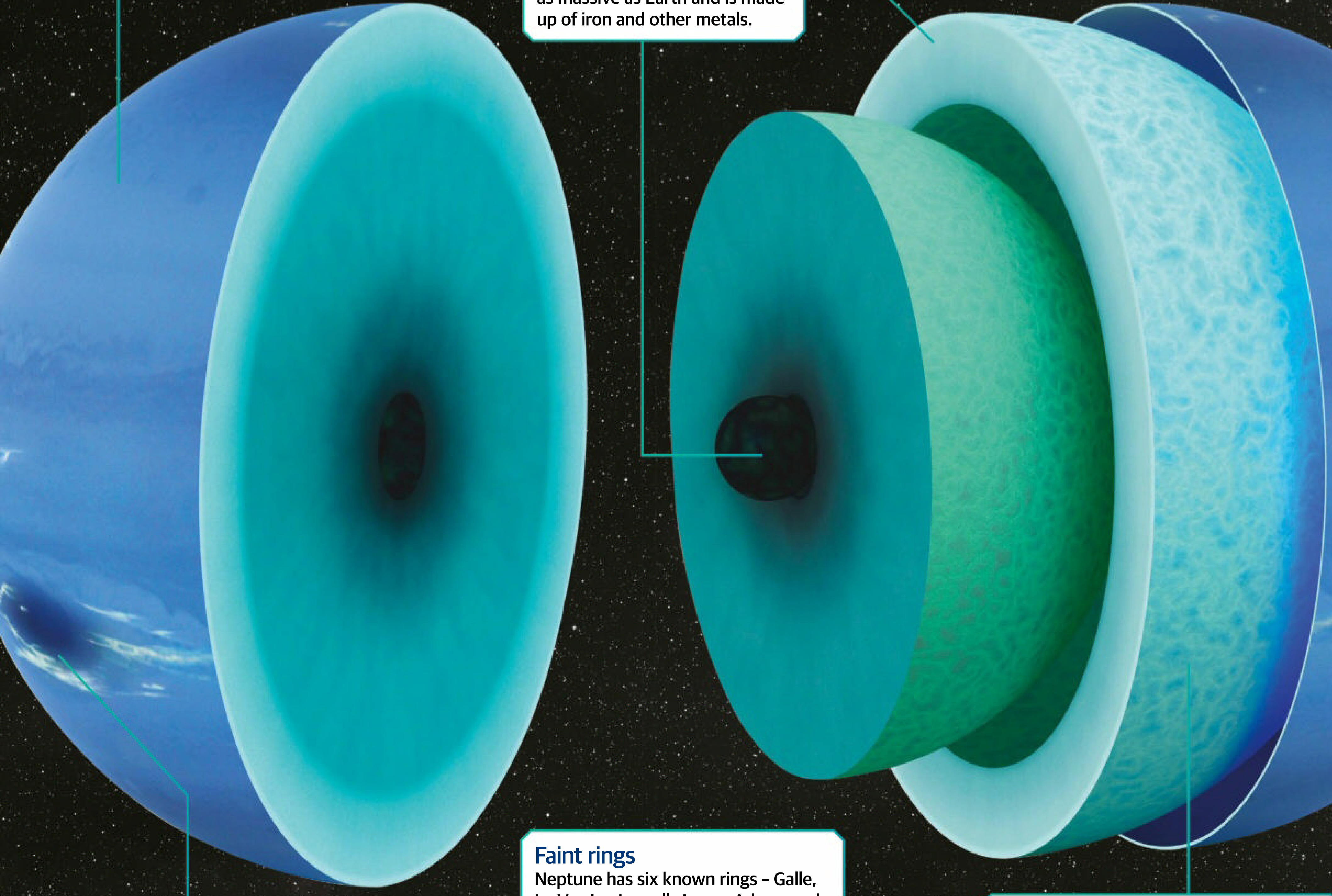
Unlike Uranus, which emits the same amount of heat it absorbs from the Sun, Neptune emits two-and-a-half-times as much.



© NASA

Neptune's core

Neptune's structure is similar to that of Uranus. It has a rocky core estimated to be 1.2-times as massive as Earth and is made up of iron and other metals.



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Faint rings

Neptune has six known rings – Galle, Le Verrier, Lassell, Arago, Adams and one unnamed ring that shares an orbit with the moon Galatea – as well as strange clumps of dust that form broken rings called arcs. The rings were discovered in 1984.

Liquid layer

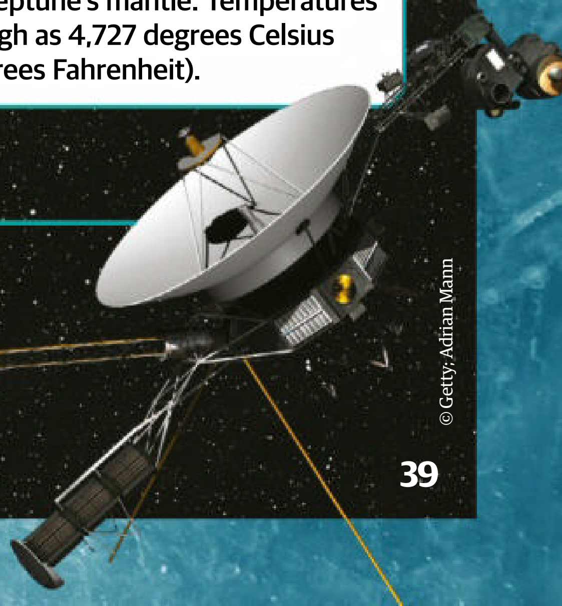
Surrounding the core is a dense liquid layer of water, ammonia and methane that serves as Neptune's mantle. Temperatures can be as high as 4,727 degrees Celsius (8,540 degrees Fahrenheit).

Great Dark Spot

This large spinning storm the size of Earth saw winds of up to 2,414 kilometres (1,500 miles) per hour before it disappeared – the fastest storm of all of the planets in the Solar System.

Measuring the temperature

Voyager 2 could only gather the upper atmosphere temperature at the cloud tops. It has been noted to be a frosty minus 218 degrees Celsius (minus 361 degrees Fahrenheit), roughly similar to Uranus at minus 213 degrees Celsius (minus 350 degrees Fahrenheit).



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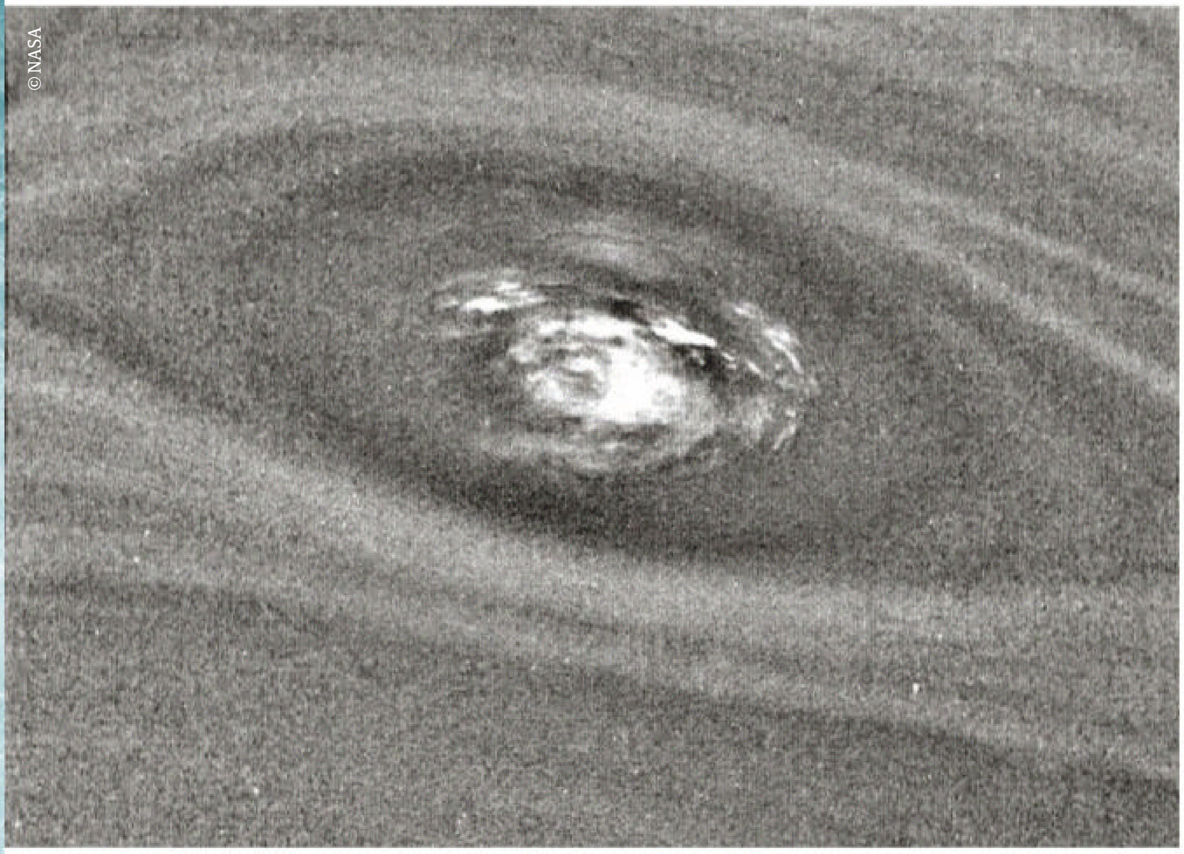
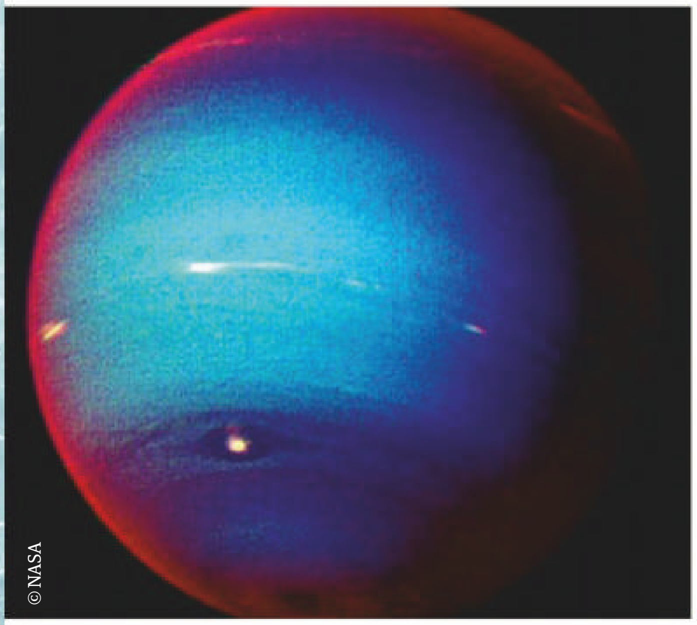


© NASA

Left: The banding around the small dark spot shows unseen strong winds - the weather on Neptune is nothing if not violent



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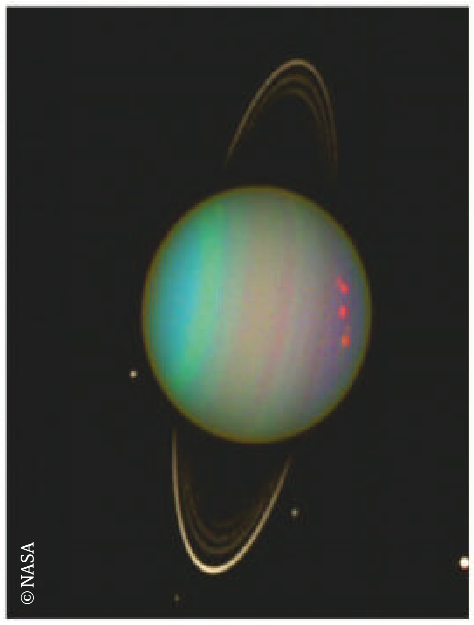
Below left: Gravitational contraction in Neptune creates thermal energy which is released out of the planet, warming it



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Below right: Could it be that Uranus has no internal heat source because a cosmic crash knocked it sideways?

this process on Uranus - perhaps due to a collision in its early history that knocked the planet on its side," Tollefson offers. And as Wong suggests: "The question becomes, 'why does Neptune have an internal heat source but Uranus does not?'."

He says there is a possibility that heat is not released from the interior at a steady rate but instead comes in 'burps'. "We may just be seeing Uranus in a quiescent period, whereas Neptune has burped more recently," he suggests. "The burps are convection, which may happen in discrete episodes separated by long time periods, but we may not know if it works this way for sure unless we see one of these convective episodes take place."

It could also be an issue of Uranus being an old-timer and Neptune a younger pup. "How much heat a planet radiates depends mostly on how old it is and how quickly or slowly it releases that heat," says Dr Amy A. Simon, a NASA senior scientist for planetary atmosphere research.

"For age, all else aside, an older planet would be colder. How quickly they release depends on the interior structure and composition, cloud layers, convection and so on and that can be rather complicated.

"For example, on the gas giants there may be significant amounts of helium rain, changing the amount of heat released. For Uranus and Neptune it is possible that they are different ages or, more likely, the event that turned Uranus onto its side may have jumbled its interior structure and/or released heat faster."

So what of those winds? They are undeniably fierce, and this may have something to do with temperature. "We've speculated for a long time that the coldness of Neptune and Uranus might lead to near-frictionless conditions and so allow for faster winds," says Heidi Hammel, a planetary astronomer who has studied both planets extensively and

© NASA/ESA

Warming up for a return

The ESA and NASA have proposals for a flying visit to the Neptunian system, but they have yet to be approved

As it stands, no space agency has any firm plans in place to visit Neptune and its system. There have been a number of proposals, but future missions remain unapproved and some, such as the Neptune Orbiter and Argo missions, have long been cancelled.

One of the most promising is ODINUS, standing for Origins, Dynamics and Interiors of the Neptunian and Uranian Systems. It had been due to launch an orbiter called Freyja in 2025 with the intention of exploring the interior, magnetosphere and atmosphere of Neptune, accompanied for much of he journey by Freyr, which scientists intend to go as far as Uranus.

As proposals continue to be discussed, however, the mission, if selected, would now launch in 2034 and, given it would take 16 years to reach its destination – the distance is, after all, 4.5 billion kilometres (2.8 billion miles) – then we can't expect to see any results until 2050.

Should it get the go-ahead from the European Space Agency, though, it would also investigate Triton, making good use of its six instruments. These would include a wide- and narrow-angle camera, a VIS-NIR image spectrometer, a magnetometer, a mass spectrometer, a Doppler spectro-imager to take seismic measurements and a microwave radiometer.

Meanwhile, NASA has proposed a single flyby of Neptune in 2038 using a spacecraft called Trident. If approved it would form part of NASA's Discovery program and concentrate on Triton, looking at its plume activity and obtaining a comprehensive map of its surface. Much depends on current NASA priorities, however.

> "Voyager's measurements show Neptune emits more than twice as much heat as it absorbs from the Sun" **Anthony D. Del Genio**

who was part of the team imaging Neptune from Voyager 2.

By this she means there are no mountains, hills or other shapes across the Neptunian landscape slowing the winds. But is there any relation between the storms and the internal heat source? "Probably," she tells us, "but there is also some delicate balance between the internal heat and the incoming sunlight."

Hammel says it is difficult to quantify these effects because of the long timescales involved. "One year on Neptune is 165 Earth years so we have not had a chance to study the planet with modern tools for very much of its seasonal cycle. You need a lot of patience - and trust in past and future generations of planetary scientists - to study the atmospheres of outer planets."

Certainly there is no denying that scientists currently have little data to work with since the ice giants are so far away. "There is no direct way of measuring the winds," Tollefson affirms. What we do know, however, is that a past belief that the strength of winds entirely depends on the amount of sunlight a planet receives is incorrect - exploration of the Solar System has put long paid to that idea.

"I guess the theory was supposed to be the greater amount of solar energy, the more wind energy, but on Earth we've known for a long time that the amount of energy received by the Sun and converted into kinetic energy in the atmosphere - that is, wind - is a tiny fraction of the total. It's something like one per cent," says Del Genio. "But Earth is a very inefficient heat engine, and it doesn't give you much bang for the buck. One reason is that it has a solid surface that dissipates wind energy by friction, whereas the gas giants do not," he adds, agreeing with Hammel's explanation. "So that is one reason why all the giant plants have much stronger winds than Earth does." Yet why are Neptune's winds stronger than other planets' winds?

According to Simon, it's a mystery. "Winds are probably generated deeper than sunlight can penetrate, so a combination of internal heat and rotation likely produces them," she says, raising the issue of why Uranus and Neptune's winds don't match, given they have similar rotation rates. "It tells us something is different between them: partially internal heat or something else," she adds.

Indeed, Uranus' winds can blow up to 901 kilometres (560 miles) per hour and Neptune's 2,414 kilometres (1,500 miles) per hour, as we mentioned earlier. "They're both extremely fast and peak at speeds faster than Jupiter," says Tollefson. NASA says Jupiter's Great Red Spot can blow at 617 kilometres (384 miles) per hour. But he too says internal heat alone cannot explain the speeds, given Uranus does not generate extra heat.

"The interior structure of the planets - their masses, core sizes and radial density profiles - is extremely important for understanding the winds as we see them. How the winds form and how deep they go are questions currently being answered for

And the weather for Neptune is...

What could you expect if you were able to pay a visit to Neptune in person?

Wind warning

Expect bands of storms of up to 2,414 kilometres (1,500 miles) per hour, the fastest you'll find anywhere in the Solar System.

Wrap up warm

The estimated temperature in its upper atmosphere averages a teeth-chattering minus 218 Celsius (minus 361 Fahrenheit).

Forget the shades

x60

Sunglasses are not necessary on Neptune. Compared to Uranus, Neptune receives 60 per cent less sunlight.

Hint of cloud

Clouds of ammonia and hydrogen sulphide exist at higher pressures, with clouds of hydrogen sulphide, ammonium sulphide and water farther down.

Grab an umbrella

There is a theory that diamond rain falls on Neptune as carbon atoms are squeezed at extremely high pressures.

Below: Antarctica is Earth's coldest, driest and windiest continent. The coldest temperature ever recorded here was -89.6°C (-129.3°F), making it significantly warmer than both Uranus and Neptune

© Jason Auch

© NASA

Left: There have been several proposals for a craft to visit the ice giants

Below: Uranus is considered to have unusual atmospheric behaviour

> “The interior structure of the planets is extremely important for understanding the winds as we see them” **Joshua Tollefson**

Jupiter and Saturn thanks to the Juno and Cassini spacecraft. This is due to the extremely good gravitational data they've obtained, which means good models for the interior structure can be made.

“But the available data is worse on Uranus and Neptune - only Voyager 2 flew by these planets up close in the 1980s. However, modellers suggest that the winds of the ice giants are confined to shallow depths in the upper layers of their atmospheres. This may suggest that the fast winds we see on Uranus and Neptune are at least partly due to the latent heat release of condensation for materials like water.”

Del Genio also questions the available data. He explains that when we measure winds on Neptune, we look at one specific altitude. “The winds at other altitudes may be slower or faster,” he tells us, “but we don't know because we have never dropped probes into the atmospheres of most of the outer planets.”

With Jupiter he argues that one probe was dropped into a single location at one time. “Winds on Earth are generally pretty slow, but up near the tropopause where the jet stream is, they're a lot faster, and when a hurricane passes by they're a lot faster still. We all - scientists included - tend to make global generalisations from sparse data, and we should be careful not to.”

Indeed, he says the general thing we can say about wind is that it is caused by pressure differences between two latitudes, and that the size of those differences, allied with the strength of the friction in a particular atmosphere, is what determines its speed. One thing's for sure, the storms can last a few years.

“Since we started monitoring with Hubble every year we have seen two new ones and - pieced together with older Hubble observations - we think a new one forms every five years and lasts a few years,” says Simon. “Brighter clouds come and go more frequently and are visible to ground-based telescopes, especially in the infrared.”

What Neptune and Uranus show is that planets which form in similar conditions can provide two extremes. Simon says this helps us constrain models of how these planets form and give clues about the Solar System's overall formation. “They should also help us better understand deeper circulation, given they are so far from the Sun.”

Hammel agrees: “It adds to our knowledge of the physics and chemistry in planetary atmospheres and helps us understand our own Earth a little better, since the physics and chemistry operate in the same way whether here on Earth or on distant Neptune,” she said.

And yet, more research is desperately needed. Galileo descended into the atmosphere of Jupiter to measure its winds directly and how they change with altitude in the late-1990s, but until another spacecraft heads to Neptune, Tollefson argues, we are stuck tracking cloud features to estimate wind speeds on this particular giant.

“All of this tells us that we haven't explored enough; we've had one flyby of Uranus and Neptune 30 years ago by Voyager,” Del Genio says. “But the formation and evolution of our Solar System is much more interesting than people originally thought they were. Given the small amount of data we have, however, its a forensic investigation with few clues.”

The theories

Just why is Neptune warmer than Uranus?

It isn't. Uranus is colder

This may sound contrary, but when you look at the data, Uranus is the anomaly. It should be warmer than Neptune but it's about the same temperature, even though it is closer to the Sun. And that's because Uranus does not have an internal heat source. Why? Well, that's another matter…

Uranus was knocked sideways

Was a catastrophic event to blame – Uranus being knocked on its side? It's a possibility, but as Dr Anthony D. Del Genio of the NASA Goddard Institute for Space Studies says: “People still argue about the impact event that formed our Moon, so if we haven't settled that, imagine how much harder it is to figure out the history of Uranus, which we've visited once and looked at through telescopes.”

Neptune has a strong internal heat source

We know that Neptune emits 2.6-times as much heat as it absorbs – that's higher than Jupiter (1.6) and Saturn (2.3) – so that is a possible explanation for it being warmer than Uranus. But not as a standalone theory, perhaps: Uranus emits no more heat than it receives, so that has to be taken into account as well.

Neptune's internal heat causes winds

The storms on Neptune are likely related to the internal heat. As Heidi Hammel points out, there could be a relationship between the winds' depth and their speed. In truth, until more data than that gleamed from Voyager 2 and through telescopes is gained, we're going to remain in the dark to a large degree.

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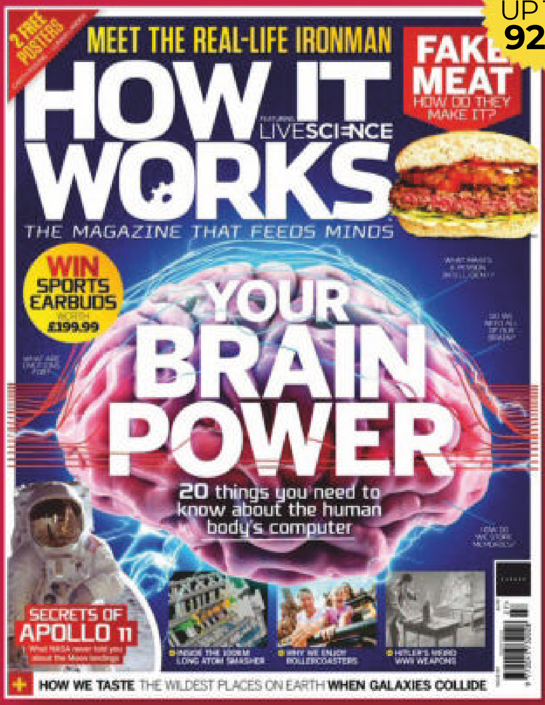
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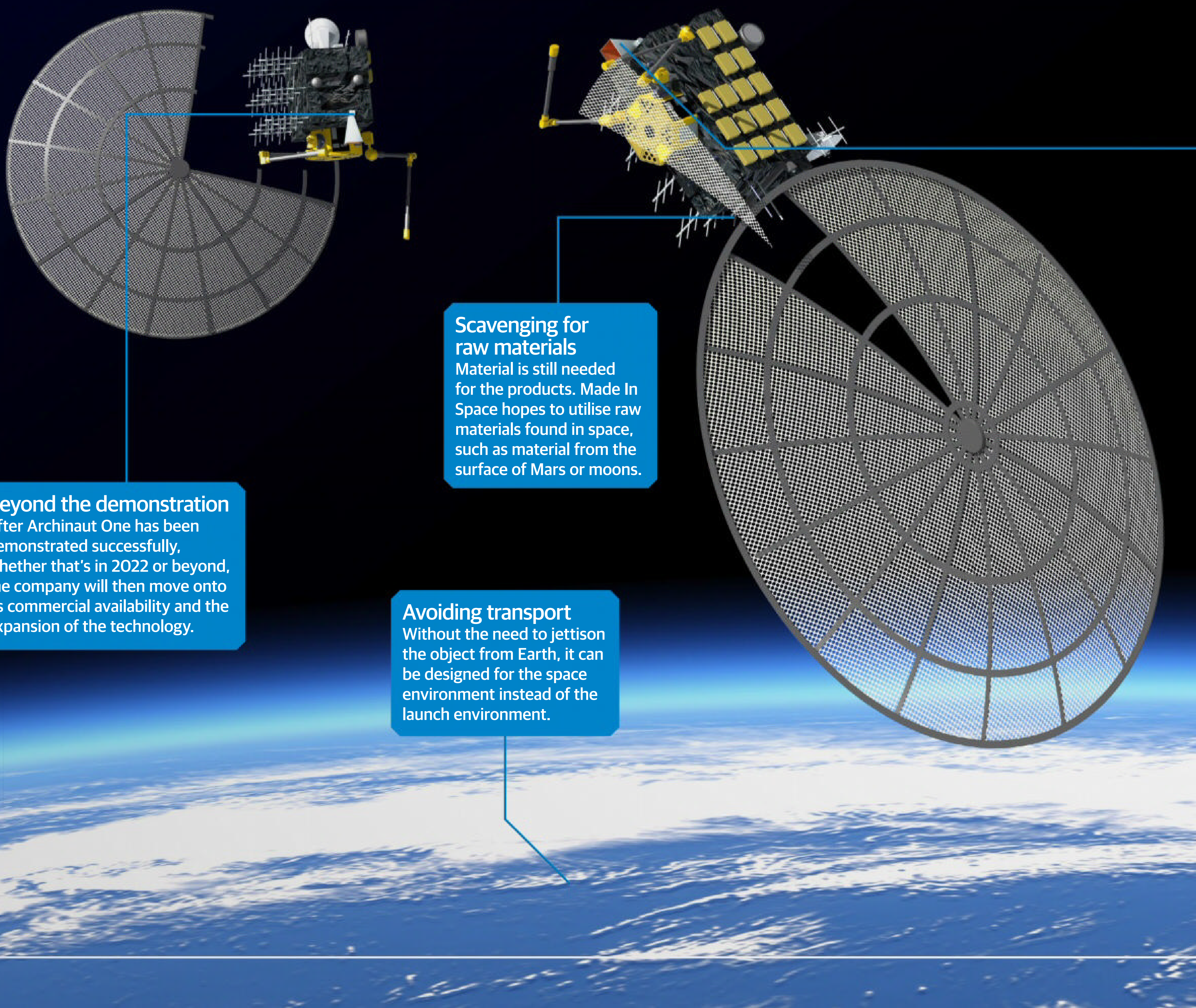
ARCHINAUT THE 3D SPACE PRINTER

Manufacturing company Made In Space is preparing to revolutionise space-based construction with the introduction of a robotic architect



Scavenging for raw materials
Material is still needed for the products. Made In Space hopes to utilise raw materials found in space, such as material from the surface of Mars or moons.

Beyond the demonstration
After Archinaut One has been demonstrated successfully, whether that's in 2022 or beyond, the company will then move onto its commercial availability and the expansion of the technology.

Avoiding transport
Without the need to jettison the object from Earth, it can be designed for the space environment instead of the launch environment.

> "The company is working towards actually building spacecraft and other components in low-Earth orbit"

Imagine a future where you don't have to build and assemble a spacecraft on Earth before you blast it into space; what if you could just build it in space? That would save a lot of money on rocket fuel and most certainly take away the risk of having it destroyed in a failed launch. Well that may soon be the case, as NASA has recently injected funding into a company, Made In Space, who plan to produce a demonstrative spacecraft that will be 3D printing objects by 2022.

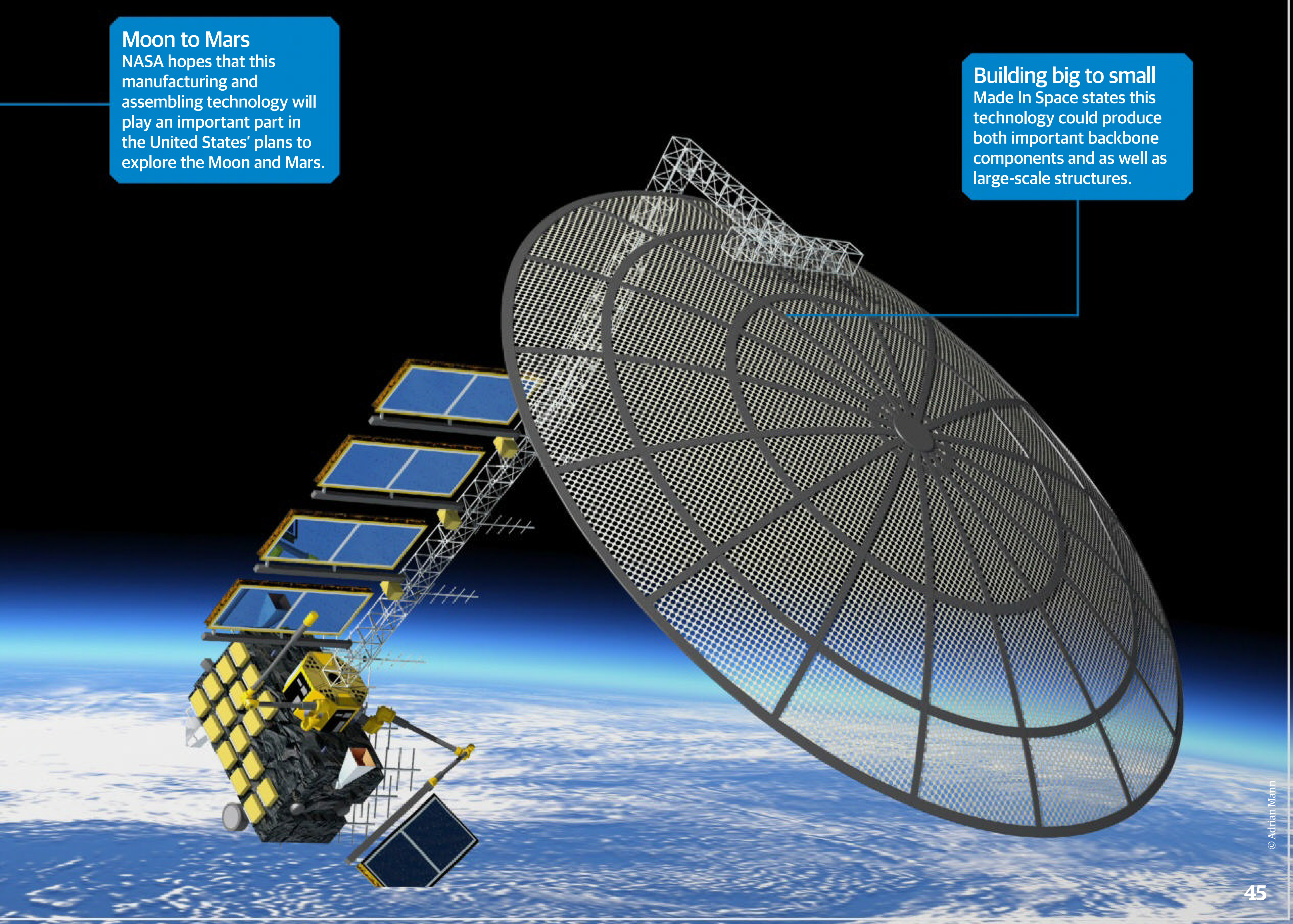
Made In Space is a company that specialises in space-based manufacturing, having already had previous business with NASA in regards to two 3D printers previously sent to the International Space Station. Now the company is working towards actually building spacecraft and other components in low-Earth orbit. As of 12 July 2019 this private-public partnership has taken a massive step forward in doing so, as NASA green-lit the funding of the demonstration craft known as 'Archinaut One'.

With $73.7 million (around £60 million) at Made In Space's disposal courtesy of NASA's 'tipping points' technology contract, the company has been able to move forward with the second phase of its plans for Archinaut, which is actual dispatch and testing in space, having only previously tested the technologies – successfully, it should be stated – in a thermal vacuum chamber on Earth. These chambers are the closest thing scientists and engineers have to space - but it isn't quite the same.

The plan behind Archinaut One is to build a spacecraft capable of 3D printing two ten-metre (32-foot) long beams when placed in low-Earth orbit. As time ticks away these beams will deploy solar arrays that are capable of generating five-times as much power as traditional solar panels of that size.

"In-space robotic manufacturing and assembly are unquestionable game changers and fundamental capabilities for future space exploration," said Jim Reuter, associate administrator of NASA's Space Technology Mission Directorate (STMD). "By taking the lead in the development of this transformative technology the United States will maintain its leadership in space exploration as we push forward with astronauts to the Moon and then on to Mars."

It is clear that people at both NASA and Made In Space are very excited to be making strides in such a fresh and innovative branch of space exploration and space architecture. NASA has stated four reasons why everyone should be excited, the first being that engineers could enable remote, in-space construction of important communication antennae, large space telescopes and other such complex structures. There is also its use in constructing small satellites that can deploy large surface area power systems, otherwise reserved for larger scale satellites. Thirdly, there is the matter of carrier rockets; this technology would eliminate the need for a constriction in volume. Finally, the new technology would take away the need for astronauts to complete spacewalks to attend to such matters, therefore reducing the risk to a life.



Moon to Mars
NASA hopes that this manufacturing and assembling technology will play an important part in the United States' plans to explore the Moon and Mars.

Building big to small
Made In Space states this technology could produce both important backbone components and as well as large-scale structures.

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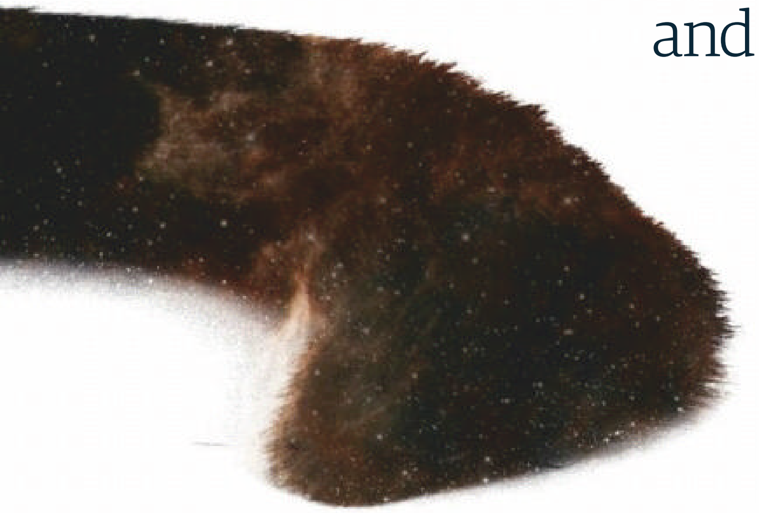
IS THE UNIVERSE ONE BIG SCHRÖDINGER'S CAT ?

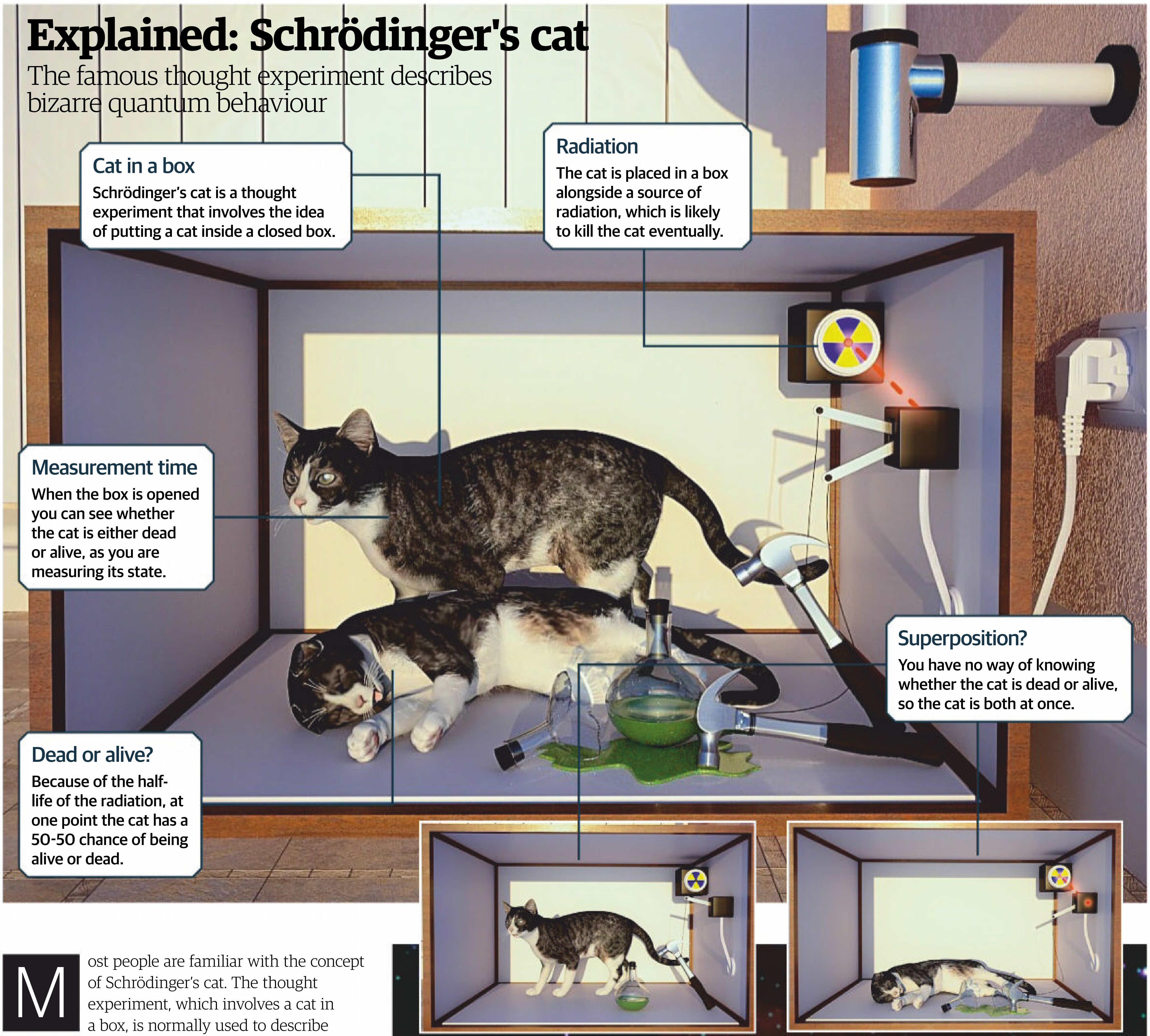
Physicists are suspecting that space and time could be both dead and alive

Reported by Abigail Beall



Explained: Schrödinger's cat

The famous thought experiment describes bizarre quantum behaviour



Cat in a box
Schrödinger's cat is a thought experiment that involves the idea of putting a cat inside a closed box.

Radiation
The cat is placed in a box alongside a source of radiation, which is likely to kill the cat eventually.

Measurement time
When the box is opened you can see whether the cat is either dead or alive, as you are measuring its state.

Superposition?
You have no way of knowing whether the cat is dead or alive, so the cat is both at once.

Dead or alive?
Because of the half-life of the radiation, at one point the cat has a 50-50 chance of being alive or dead.

Most people are familiar with the concept of Schrödinger's cat. The thought experiment, which involves a cat in a box, is normally used to describe quantum mechanics. The cat is placed in a box alongside a source of radiation, which is likely to kill the cat eventually. Let's say at one point, the cat has a 50-50 chance of being alive or dead. The box is closed, and you have no way of knowing whether the cat is dead or alive until you open the box. Schrödinger said the cat is both dead and alive until the box is opened, when it becomes either dead or alive depending on what you can see.

This analogy was developed to describe particles in quantum mechanics, when the position of a particle is unknown. The particle could have a 50 per cent chance of being in two different positions, or states, and it is said to be in both at the same time until the position is measured, at which point it 'decides' where it is and becomes 100 per cent in that position. Strangely, the act of measuring its position has an effect on the position of the particle. But what could this possibly have to do with the

If the cosmological constant was smaller, everything would collapse under its own gravity and stars would not form

©NASA

> “There are parts of the universe where the cat is alive, where the cosmological constant is just right” **Steven Weinberg**

universe? It’s all to do with a special number called the cosmological constant, which describes the energy density of space.

“The universe could well be like a giant Schrödinger’s cat,” theoretical physicist Steven Weinberg told *Discover*. “There are parts of the universe where the cat is alive, where the cosmological constant is just the right level and there are scientists there observing it and asking questions. And there are parts of the universe where the cat is dead - where the cosmological constant is too small or too large and therefore there is no life and no scientists asking questions about the universe.”

First, we need to understand what the cosmological constant actually is. There is a set of numbers, known as the fundamental constants, which play a vital role in physics in determining how things interact with each other. “Testing their constancy is in itself a test of the theories we use,” says Ana Catarina Leite, who studies fundamental constants at the Universtiy of Porto in Portugal. “They allow us to test the domain of their validity, and if their constancy doesn’t hold true, new physics should arise. If we detect a variation, either in time or by local environment conditions, then we would expect that they impact our current interpretation of the universe.”

The cosmological constant is one of these fundamental constants, and it is related to the equations used in Einstein’s theory of general relativity. In the equations the term acts to counteract the gravitational pull of matter, and so it has been described as an anti-gravity effect. It is also called the vacuum energy of space, or the energy density. It’s linked to the amount of force that is pushing the universe outwards by a mysterious force called dark energy.

Dark energy has been dominating the expansion of the universe for roughly a third of its 13.8 billion year lifetime, causing the expansion to accelerate. We know this from looking at distant objects in

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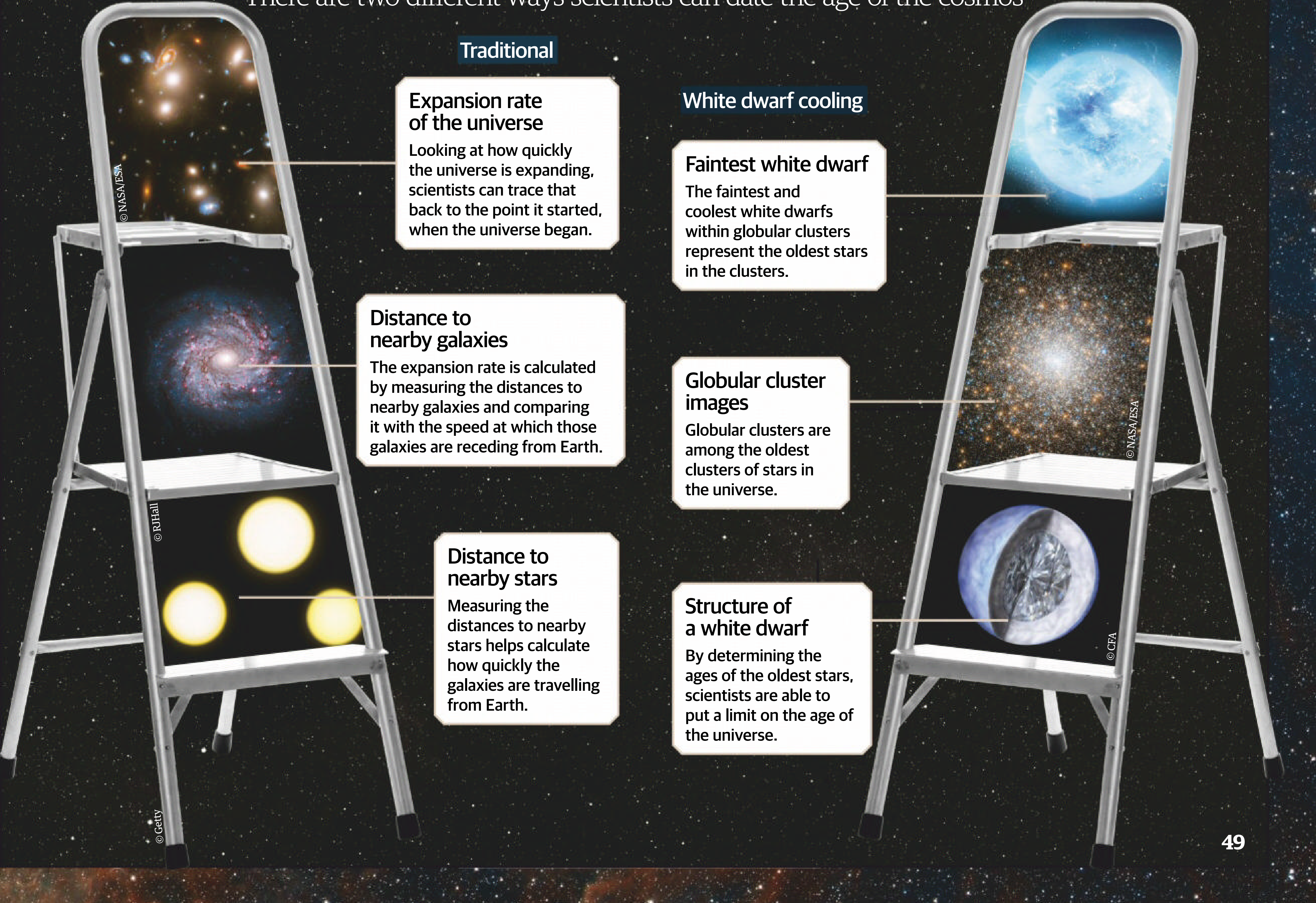
Pinpointing the age of the universe

There are two different ways scientists can date the age of the cosmos



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Traditional

Expansion rate of the universe

Looking at how quickly the universe is expanding, scientists can trace that back to the point it started, when the universe began.

Distance to nearby galaxies

The expansion rate is calculated by measuring the distances to nearby galaxies and comparing it with the speed at which those galaxies are receding from Earth.

Distance to nearby stars

Measuring the distances to nearby stars helps calculate how quickly the galaxies are travelling from Earth.

White dwarf cooling

Faintest white dwarf

The faintest and coolest white dwarfs within globular clusters represent the oldest stars in the clusters.

Globular cluster images

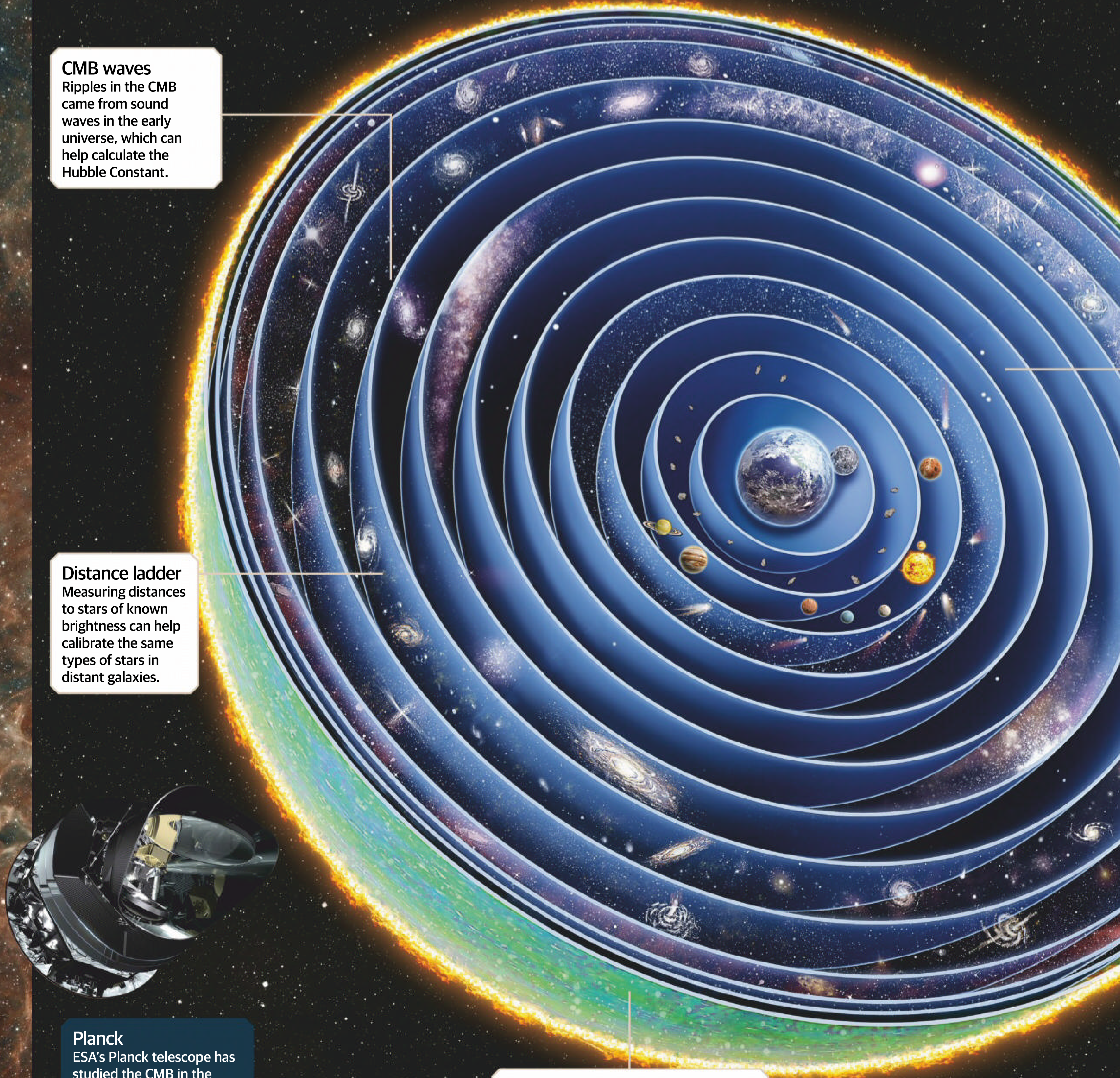
Globular clusters are among the oldest clusters of stars in the universe.

Structure of a white dwarf

By determining the ages of the oldest stars, scientists are able to put a limit on the age of the universe.

Clocking the cosmos

The universe is expanding quickly, according to observations



CMB waves
Ripples in the CMB came from sound waves in the early universe, which can help calculate the Hubble Constant.

Distance ladder
Measuring distances to stars of known brightness can help calibrate the same types of stars in distant galaxies.

Planck
ESA's Planck telescope has studied the CMB in the most detail yet, providing a clear picture of the radio waves left over from after the Big Bang.

Cosmic microwave background
The CMB has clues to the early stages of the universe, meaning we can use it to measure distances.

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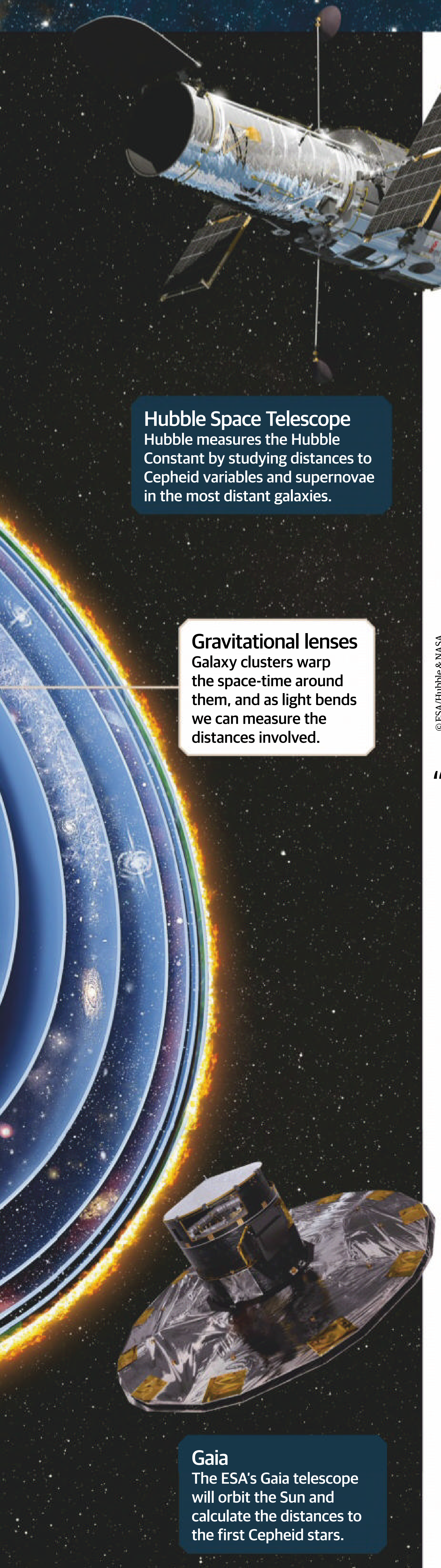

Hubble Space Telescope
Hubble measures the Hubble Constant by studying distances to Cepheid variables and supernovae in the most distant galaxies.

Gravitational lenses
Galaxy clusters warp the space-time around them, and as light bends we can measure the distances involved.

Gaia
The ESA's Gaia telescope will orbit the Sun and calculate the distances to the first Cepheid stars.

If the cosmological constant was any bigger, galaxies would not stick together through their gravity

© ESA/Hubble & NASA

"The cosmological constant has a small, non-zero value that causes the universe to accelerate" **Sabine Hossenfelder**

space, which is like looking back in time. The cosmological constant is the simplest explanation we have for dark energy, the force that is causing this acceleration, but there's a problem.

"The value of the cosmological constant is infamously the worst prediction ever made using quantum field theory; the math says it should be 120 orders of magnitude larger than what we observe," says theoretical physicist Sabine Hossenfelder, writing in *Forbes*. "But that the cosmological constant has a small, non-zero value that causes the universe to accelerate is extremely well established by measurement."

There are different ways to measure the cosmological constant, and using these different ways, researchers get different results. One is by measuring the cosmic microwave background (CMB), radio signals left over from shortly after the Big Bang. Another is to use the redshift from distant stars and galaxies to measure how fast they are moving away from us. Redshift is the amount the wavelength of light changes as its source moves away, caused by the Doppler effect, the very same reason an ambulance siren changes pitch when it moves away from you. Using these two different methods gives different results, different enough that the probability it was a random fluctuation is just one in a thousand.

One answer to why these measurements might vary is that the cosmological constant changes over time. This creates a kind of Schrödinger's cat analogy with the entire universe: parts of it are alive and parts are dead. If the cosmological constant was too large, nothing would stick together, and galaxies would not exist. If it were too small, everything would collapse under its own gravity. This means when it is just right, life as we know it can exist.

If the universe is indeed one huge Schrödinger's cat, the part of it that is alive is where we live. Within this part we have our own versions of Schrödinger's cat occurring daily, when physicists experiment with quantum mechanics. But the fate of the cat might not be written in the stars according to a recent study, which suggests we can not only

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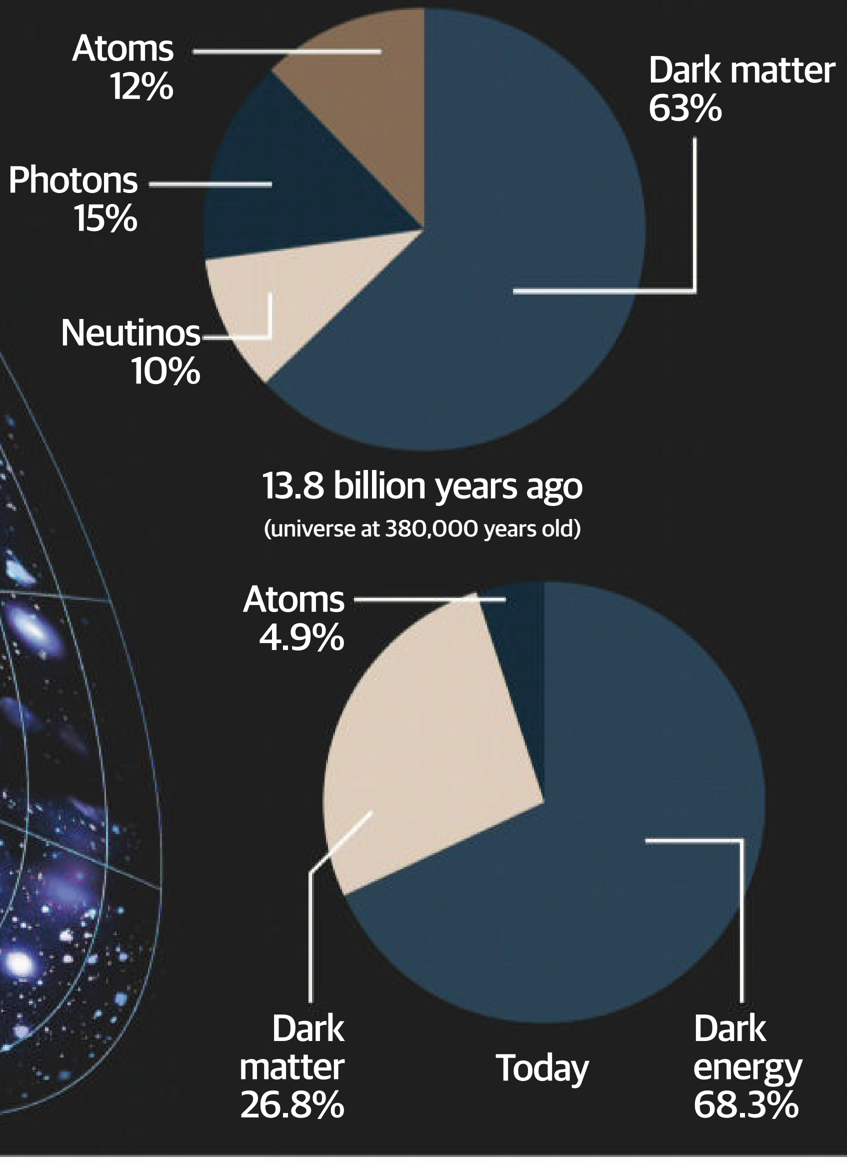
Cosmic make up

Now vs. 13.8 billion years ago



predict whether it will be dead or alive, but we can 'reverse' the process too - saving Schrödinger's cat.

In June this year, researchers at Yale University in the US published a paper in the journal *Nature*. It said the process of the cat 'jumping' to being dead or alive when the box is opened, which refers to the process of a quantum particle jumping into a state, known as a quantum jump, is not instantaneous. Instead, it happens very fast.

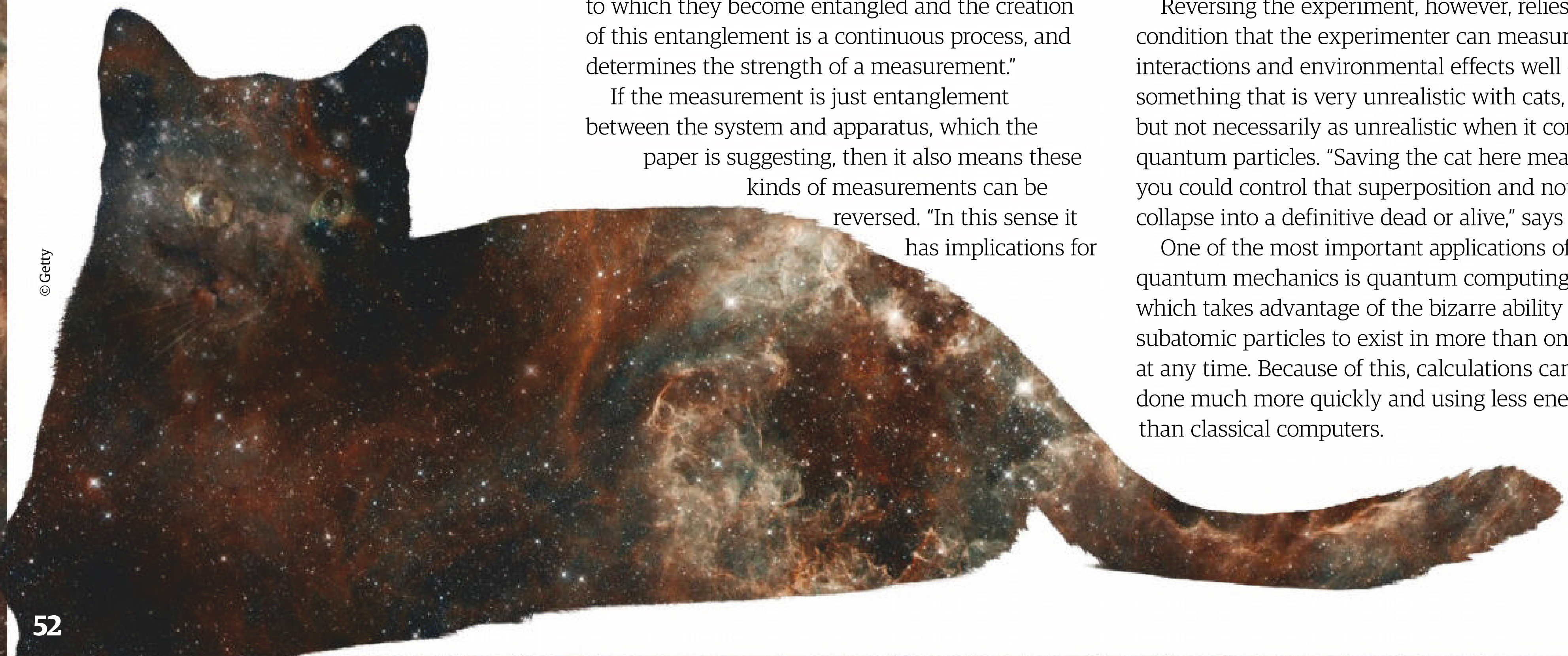
"This is a very beautiful experiment that demonstrates, in my view, that measurement is a continuous process and not an abrupt jump as the name 'quantum jump' might suggest," says Vlatko Vedral from the University of Oxford, who was not involved in the study. "What I think it shows is that a measurement of a quantum system is just an entangling operation to another quantum system - call it the apparatus," he says. "The degree to which they become entangled and the creation of this entanglement is a continuous process, and determines the strength of a measurement."

> "Saving the cat here means that you could control that superposition and not let it collapse into dead or alive" **Vlatko Vedral**

If the measurement is just entanglement between the system and apparatus, which the paper is suggesting, then it also means these kinds of measurements can be reversed. "In this sense it has implications for Schrödinger's thought experiment, as it implies that the 'dead and alive' state could be reversed in the same way that any other quantum superposition could," says Vedral. This is where the idea of saving the cat comes from.

Reversing the experiment, however, relies on the condition that the experimenter can measure all interactions and environmental effects well enough, something that is very unrealistic with cats, he says, but not necessarily as unrealistic when it comes to quantum particles. "Saving the cat here means that you could control that superposition and not let it collapse into a definitive dead or alive," says Vedral.

One of the most important applications of quantum mechanics is quantum computing, which takes advantage of the bizarre ability of subatomic particles to exist in more than one state at any time. Because of this, calculations can be done much more quickly and using less energy than classical computers.



© Getty

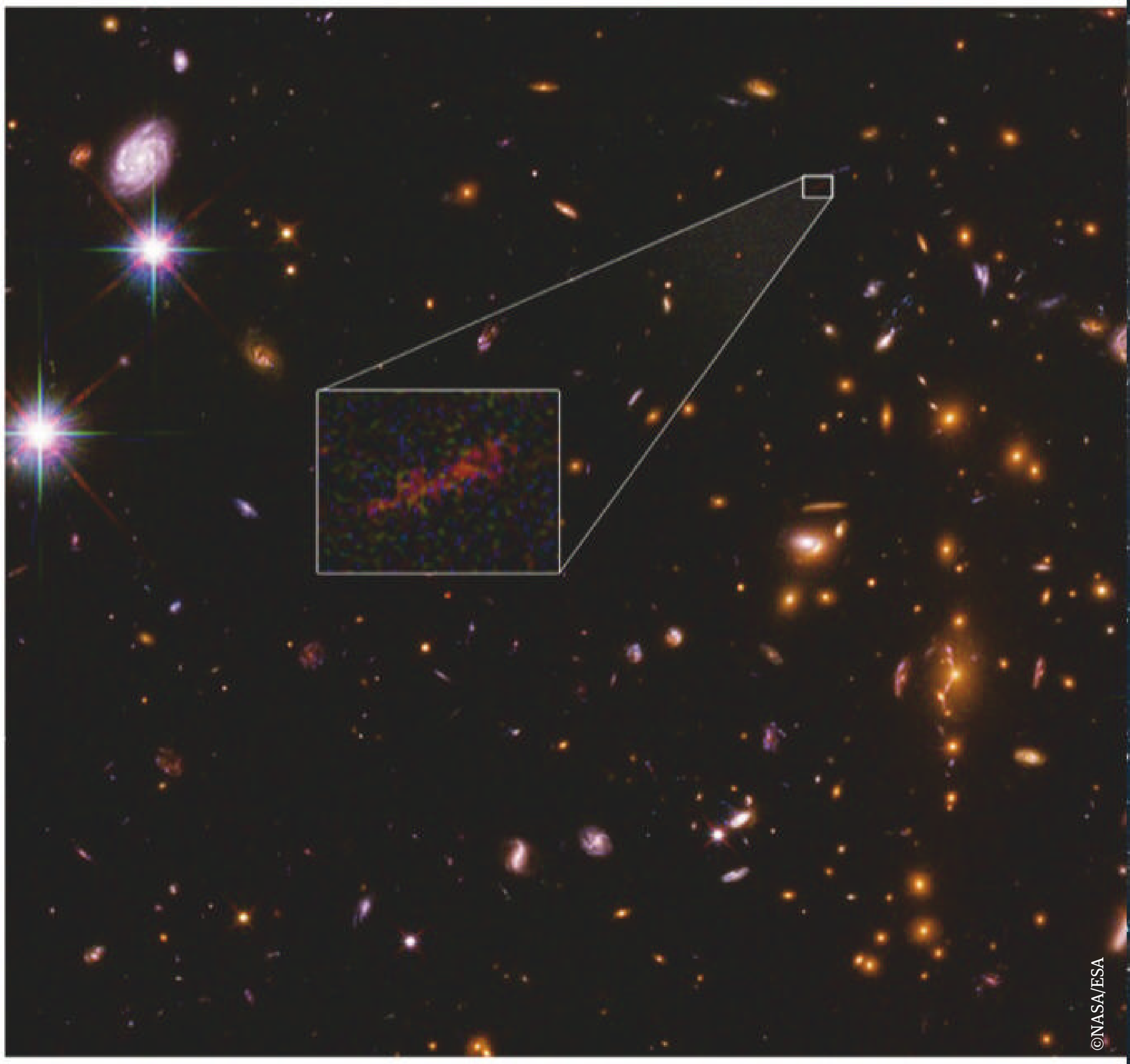
In classical computing a bit is a single piece of information that can exist in two states - 1 or 0. Quantum computing uses quantum bits, or 'qubits' instead. Unlike a usual bit they can store much more information than just 1 or 0, because they can exist in any superposition of these values - they can be 1 and 0 at the same time.

Being able to save Schrödinger's cat has huge implications for quantum computing; it means we can control the behaviour of qubits. "This paper might pave the way towards a higher degree of quantum control of quantum systems," says Vedral, "which is clearly needed to utilise quantum physics at the macroscopic level, be it to create cats or to perform large scale quantum computations."

It might seem like this idea of saving Schrödinger's cat has nothing to do with the analogy of Schrödinger's cat in relation to the universe. But quantum computing is intrinsically linked to our ability to study the universe. Modelling the universe requires large-scale computing power, especially with the huge distances and times involved in simulations. Cracking quantum computing would have huge implications for what astronomers and particle physicists can simulate using the available computational power, and might even help us to understand how the cosmological constant varies across the universe, if it does at all.

Right: Measuring the redshift of distant galaxies, like the one shown, can also determine the cosmological constant

Below: If there are parts of the universe which are 'dead', there is no one there to observe the stars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TRACKING DOWN THE FIRST STARS

What flicked the switch and turned the universe's lights on? Some stellar giants are hiding at the beginning of space and time, and here's how astronomers are going to find them

Reported by Lee Cavendish

Imagine a universe that is pitch black in every direction you look. True nothingness. Even if you open your eyes, the darkness doesn't change. This was the universe 100 million years after the Big Bang, an era known as the 'Dark Ages'. After the initial 'explosion' of the Big Bang, universal expansion caused the environment to go from scorching hot to a larger, cooler field of particles. As the cosmos continued to grow and cool, energetic particles began to settle down and form the first hydrogen particles, consisting of a proton and an electron, along with helium, which is made up of two neutrons, two protons and two electrons.

From this sea of hydrogen and helium molecules – with a sprinkling of lithium molecules – uniformly distributed clumps began to emerge as gravity played its valuable part in the cosmos. The same gravity that keeps our feet on the ground created balls of hydrogen atoms that continued to grow, and the density increased. In the next 10 to 100 million years the balls grew bigger and bigger until nuclear fusion ignited deep within their cores, and in that instant the universe left behind the Dark Ages as the first stars were born. These were the first generation of stars to exist, and can also be referred to as 'Population III' stars, but astronomers have yet to see their ancient light from any point of the cosmos, so how do we know what they even look like?

"Interestingly, our expectations and predictions for what the first stars should look like have somewhat evolved a bit over the last 20 years," Dr David Sobral, a reader in astrophysics at the University of Lancaster, United Kingdom, tells **All About Space**. "We expected first-generation stars to be very massive – up to 100- to 1,000-times as massive as our Sun – which would imply they should be incredibly large, incredibly blue – technically, very ultraviolet, at a level where if the Earth were to orbit such a star, no amount of sunscreen would ever protect us, not even for a few seconds – and have lifetimes of just a few million years, and definitely much shorter than stars which are Sun-like and live for 10 billion years or so."

In other words, the first generation of stars were stellar behemoths, soaking up the untainted supply of hydrogen and helium as they burnt at unbearable temperatures. These behemoths have had a huge influence on the universe as we know it now, with two main contributions: one being the introduction into the 'reionisation' era in a cosmological sense, and the other being the creation of the very first metals – 'metals' in an astronomical sense are any elements other than hydrogen or helium.

The latter of these is closer to all of our hearts, quite literally. "We are here. We breathe oxygen, we eat carbon, we have bones made of calcium, our body uses iron to transport oxygen and keep us alive," says Sobral. "If the first generation of stars had never existed those elements would have never

I, II, III: Different stellar families

Stars can be categorised into three types based on their age and metallicity

Population I

These stars are the youngest group of stars, with the Sun included in this category. They are normally found in a galaxy's disc or spiral arms, as this is where more recent star formation occurs. They have a relatively high metallicity, containing a lot of elements heavier than hydrogen and helium.

©ESO

Population II

The middle generation of stars tend to be older, less luminous and can be found primarily in globular clusters – such as the deep-sky object Messier 2 – that are situated in the nucleus or the halo of the galaxy. They have a relatively low metallicity due to a purer interstellar medium when they formed billions of years ago.

©ESA/Hubble & NASA

Population III

The oldest population of stars that have yet to be found in the cosmos. Astronomers predict they could either be too faint to see or have already exploded and left behind neutron stars or black holes – or have left nothing at all! They would have no signs of metallicity and would be just hydrogen and helium.

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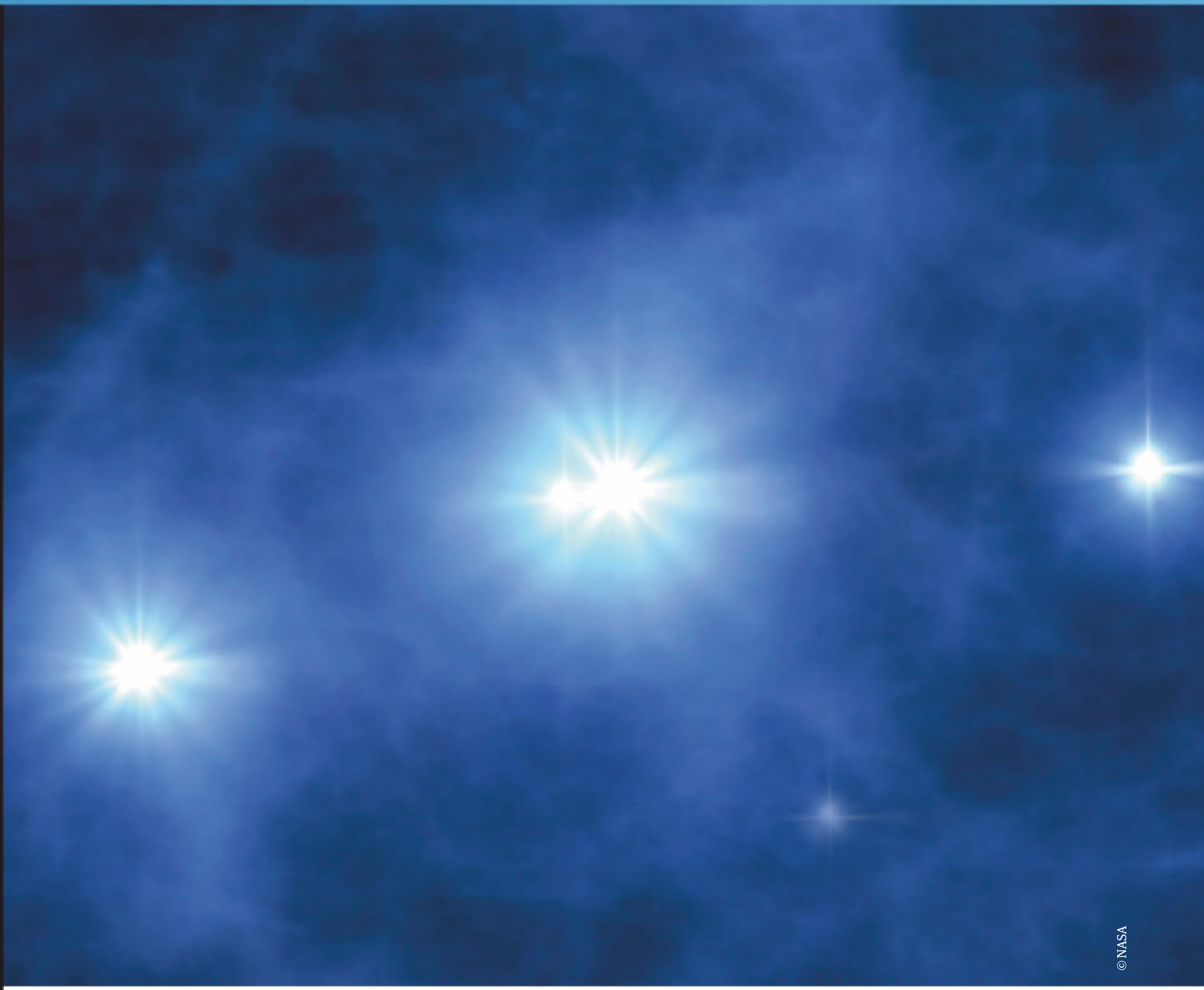


© NASA

> "Our expectations and predictions for what the first stars should look like have somewhat evolved a bit over the last 20 years" **Dr David Sobral**

existed. Subsequent generations of stars would never have formed, and the periodic table would be incredibly simple and just made of hydrogen and helium – and no living being to even think about a periodic table."

It was in the belly of these behemoths that the universe saw its first metals created via the process of nuclear fusion. These earliest stars couldn't have had planets in orbit around them, as the material required to form their planetary cores, crusts, mountains and oceans simply were not there. "First-generation stars could not form planets because there were no heavy elements, but, at least in simulations, they seem to form smaller stars around them as if they were planets, but just made of hydrogen and helium," explains Sobral. This could mean that some of these smaller Population III stars could still be hiding somewhere in the universe at the moment, but are just too faint to see.

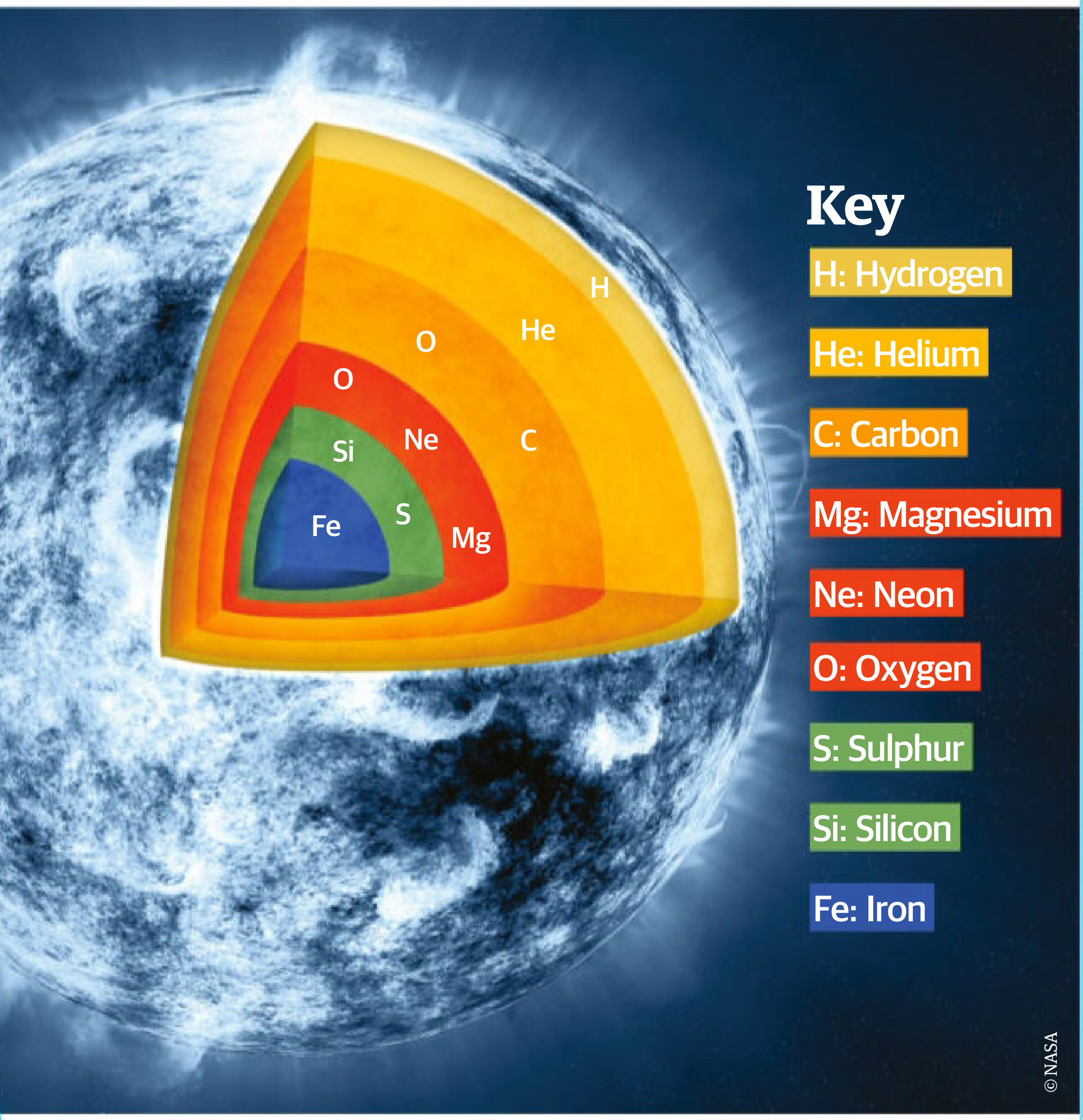
© Judd Bowman/Arizona State University

At the cores of these early stars, hydrogen and helium were being converted into carbon, oxygen, sodium, neon, magnesium and so on via the process of nuclear fusion, until the stars reached an extremely violent end. "Depending on how heavy they were when they were initially formed they have multiple scenarios, including core-collapse supernovae, pair-instability supernovae and of course black holes," Dr Daegene Koh, a postdoctoral research fellow in physics at Stanford University in California, tells **All About Space**. "There are more recent efforts to understand if the more massive black holes that formed from these Population III stars could be the seeds that eventually grew to become present-day supermassive black holes located at the centres of galaxies."

There are many different types of supernova, and the two just mentioned – core collapse and pair instability – both occur in the most massive stars, tens to hundreds of times the mass of our Sun, also known as solar masses. When a star reaches the end of its life, the star enters an internal struggle to balance out the gravitational collapse of the star with its radiation output. When the radiation stops due to lack of nuclear fusion, the collapse overwhelms the star and it begins to contract. At this point, depending on the star's mass and metallicity, the star can either shrink to the point where the core collapses under its own gravity and releases an enormous shockwave - leaving behind either a neutron star or a black hole after a core-collapse supernova - or it can contract until free electrons and positions are produced - termed as 'pair production'. This produces a pressure instability that releases the outer layers as a pair-instability supernova.

"When these stars undergo supernovae they form and release heavier elements into their surrounding areas, mixing with the so-called interstellar medium," says Koh. "After time this newly metal-enriched gas will once again undergo gravitational collapse and form the next generation of now metal-enriched stars, or Population II stars."

As mentioned previously though, the creation of new elements - and their relatively fast transformation into Population II stars - was not the only thing these stars were good for. Stepping out of the Dark Ages and into the Epoch of Reionisation is thought to have stemmed from the emergence of Population III stars. The reionisation era, in short, is when universal matter began to heat back up



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Left (clockwise): The first stars likely formed around 200 million years after the Big Bang

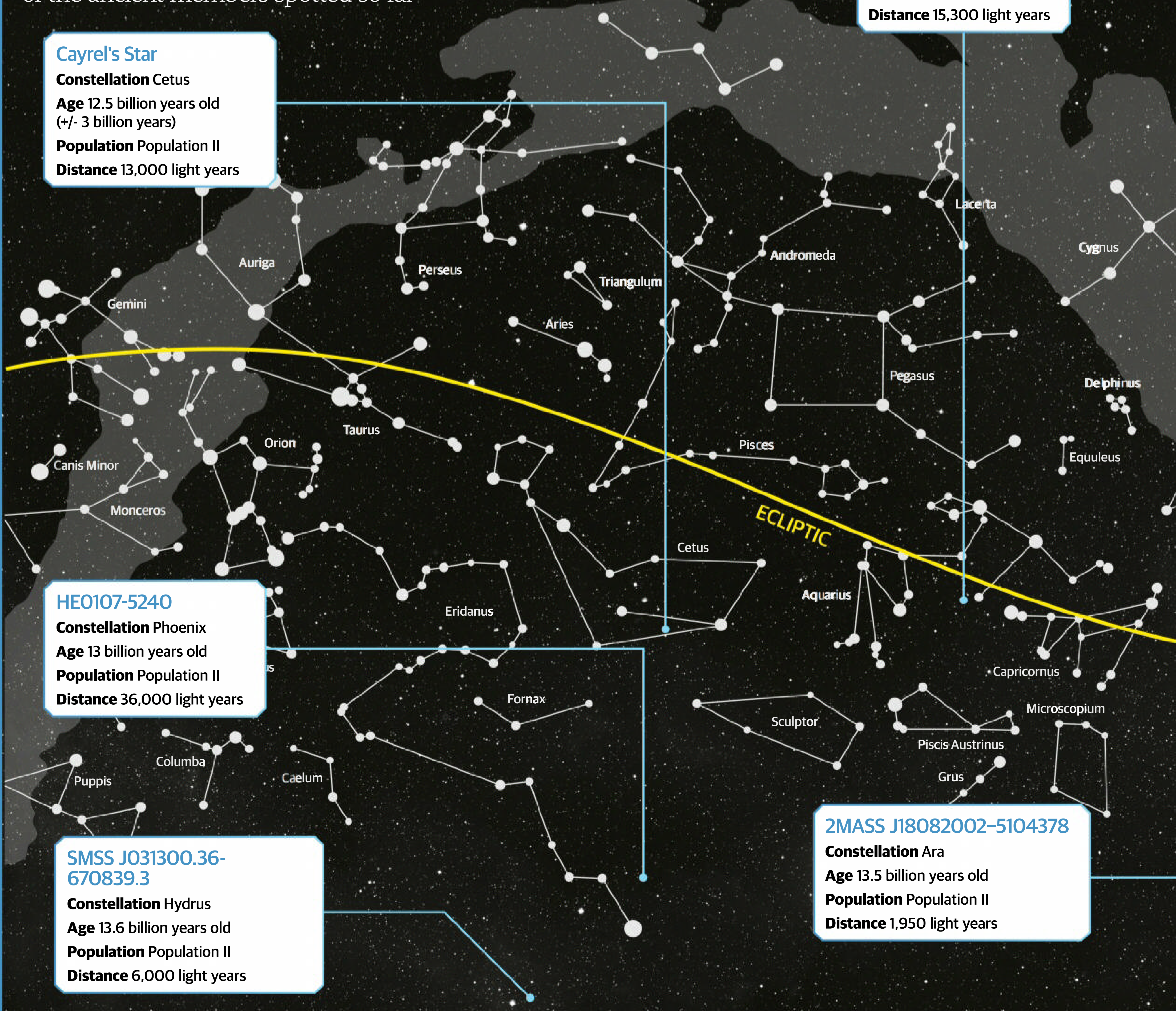
David Sobral researches ancient galaxies and galaxy formation

Nuclear fusion will eventually cause a star to contain layers of different elements, with iron being the heaviest

The EDGES project's coffee-table-sized antenna in Western Australia

The oldest known stars

About 13.8 billion years ago the universe was born, but how soon after did the stars follow? Meet some of the ancient members spotted so far



Sneden's Star
Constellation Aquarius
Age 13 billion years old
Population Population II
Distance 15,300 light years

Cayrel's Star
Constellation Cetus
Age 12.5 billion years old (+/- 3 billion years)
Population Population II
Distance 13,000 light years

HE0107-5240
Constellation Phoenix
Age 13 billion years old
Population Population II
Distance 36,000 light years

SMSS J031300.36-670839.3
Constellation Hydrus
Age 13.6 billion years old
Population Population II
Distance 6,000 light years

2MASS J18082002–5104378
Constellation Ara
Age 13.5 billion years old
Population Population II
Distance 1,950 light years

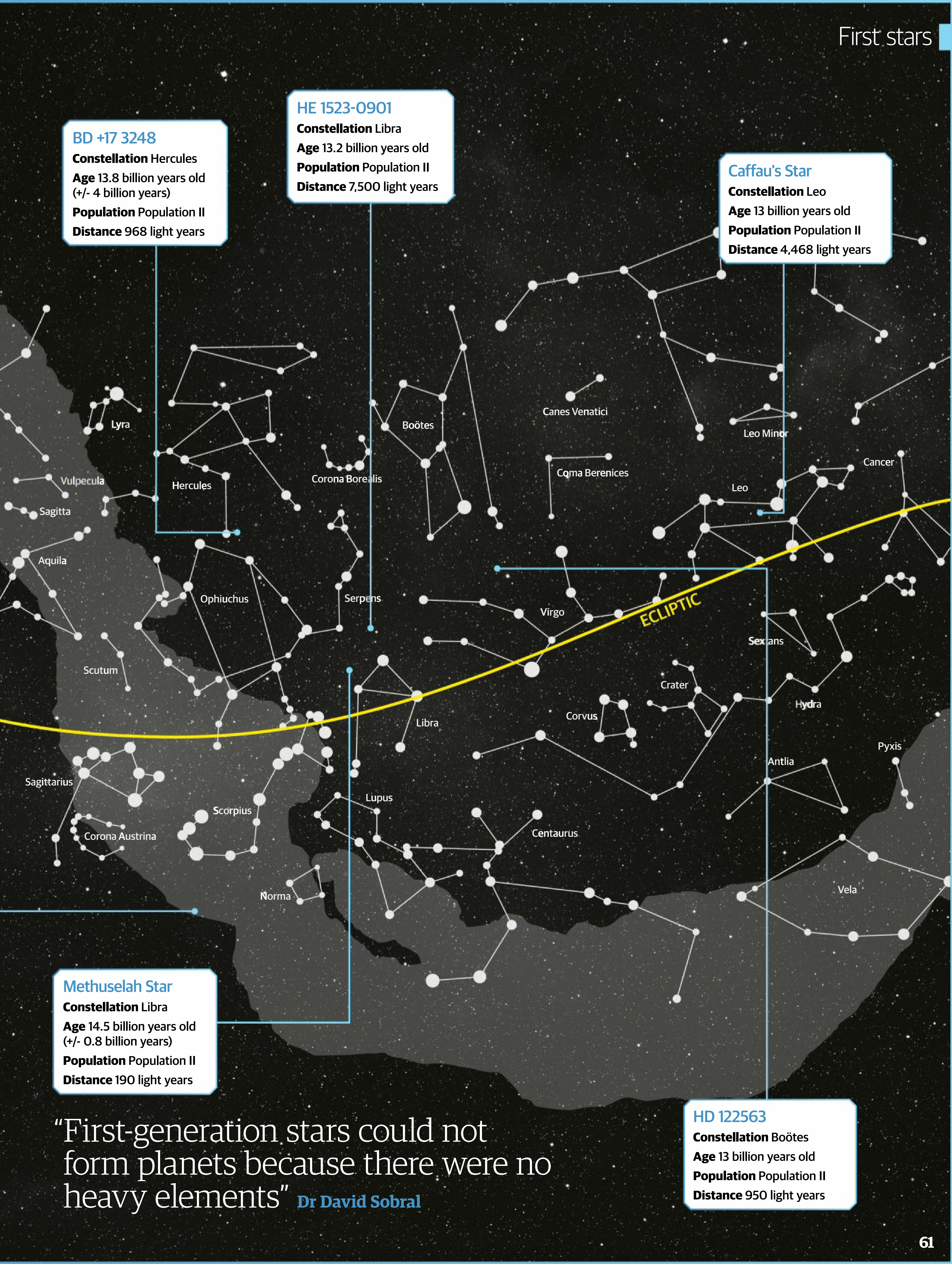
due to the creation of stars and galaxies, stripping hydrogen atoms of their electrons throughout the cosmos.

"The most massive of the first stars are thought to have kick-started the reionisation era of the universe," says Sobral. "They should have been the first objects which were hot enough to release a copious amount of highly energetic photons, capable of breaking apart hydrogen atoms in clouds nearby and also at large distances. The big limitation here is their lifetime."

Astronomers are still searching for these ancient and elusive stars, but one obstacle faced is due to the fact that although these stars are hotter and brighter than any known star, they do not live for long. It truly is the brightest stars that burn out the fastest. This makes the search for Population III stars, the first-ever stars to come to life in the universe, one of the hottest hunts in astronomy.

A team that have yielded the most recent and most exciting results are scientists working on the Experiment to Detect the Global Epoch of Reionisation Signature (EDGES) project.

"We used a single antenna – of the size of a coffee table – that looks straight up at the sky. The antenna is placed in Western Australia, where it is radio quiet," Nivedita Mahesh, a doctorate candidate at Arizona State University and a member of the EDGES team, tells **All About Space**. "This experiment is 15 years in the making. It was Professor Judd Bowman [of Arizona State University] and Alan Rogers [of the Massachusetts Institute of Technology] who designed



BD +17 3248
Constellation Hercules
Age 13.8 billion years old (+/- 4 billion years)
Population Population II
Distance 968 light years

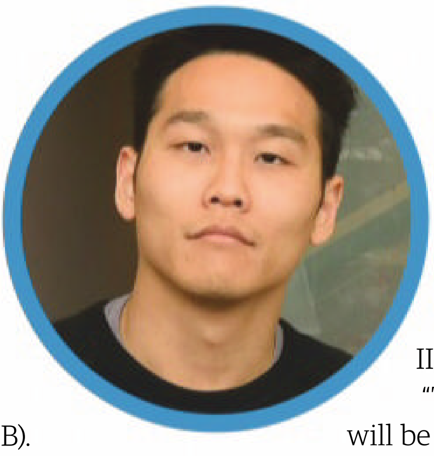
HE 1523-0901
Constellation Libra
Age 13.2 billion years old
Population Population II
Distance 7,500 light years

Caffau's Star
Constellation Leo
Age 13 billion years old
Population Population II
Distance 4,468 light years

Methuselah Star
Constellation Libra
Age 14.5 billion years old (+/- 0.8 billion years)
Population Population II
Distance 190 light years

HD 122563
Constellation Boötes
Age 13 billion years old
Population Population II
Distance 950 light years

> "First-generation stars could not form planets because there were no heavy elements" **Dr David Sobral**



and began this experiment.”

The team has been using this simple piece of equipment to study the oldest light in the universe - even older than any Population II star - which is the Cosmic Microwave Background (CMB). What the EDGES experiment is trying to find is a silhouette in the CMB data that can only be caused by the reionisation of neutral hydrogen, also known as the '21-centimetre line'. “This is an extremely difficult measurement to make because the signal we are looking for is 10,000-times weaker than any other astrophysical source in the sky, including our own galaxy,” explains Mahesh.

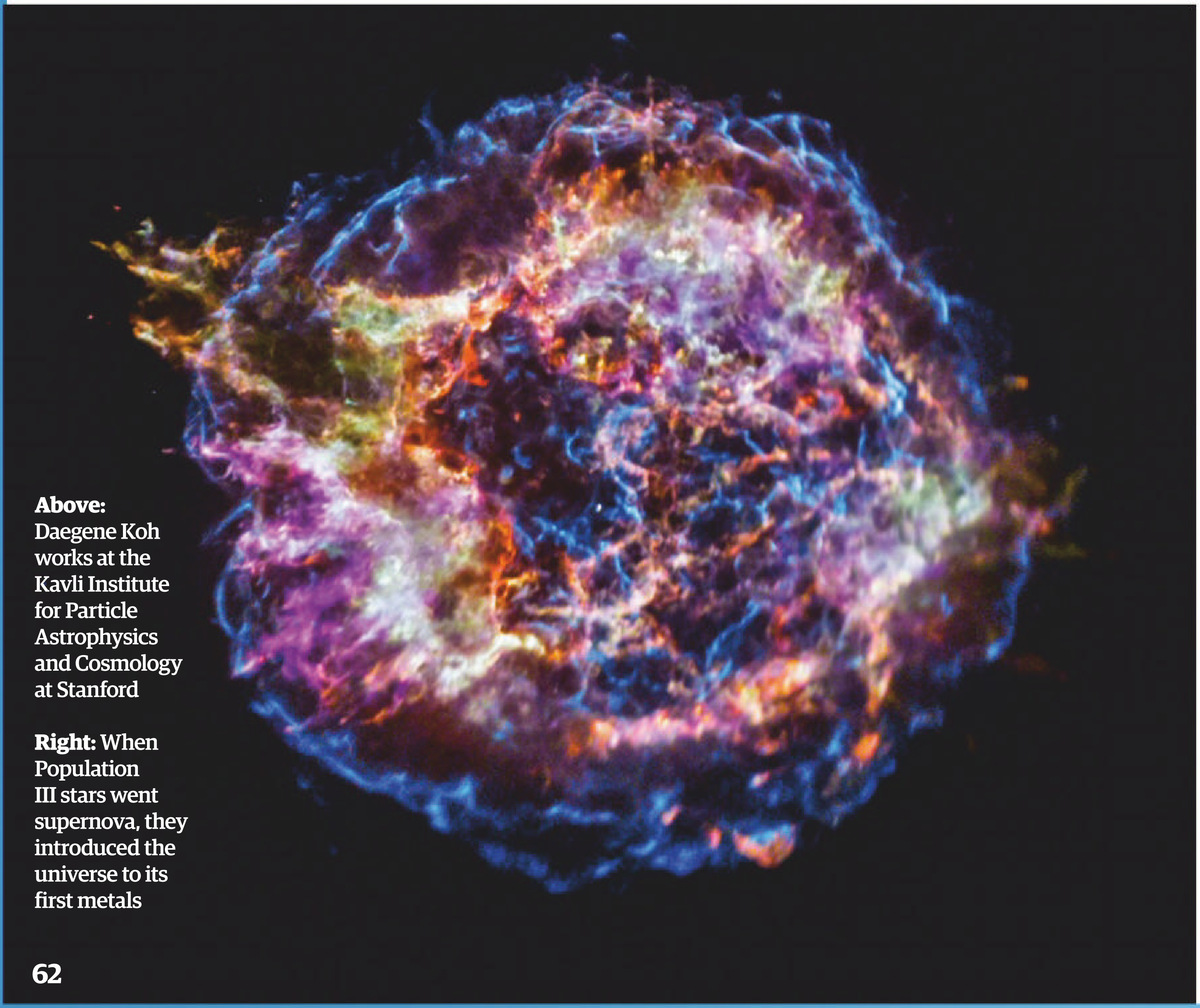
In February 2018, possibly the most exciting evidence for such an event was found. After 15 years of searching the EDGES experiment found a faint signal of hydrogen gas, in a state that could only be possible in the presence of this first generation of stars, just 180 million years after the Big Bang. While this is not definitive, it is by far the closest astronomers have come to understanding the Epoch of Reionisation and the environment that birthed the stars. In fact, this evidence indicates that the universe could have been twice as cold as astronomers previously thought, with temperatures around just three degrees Kelvin (minus 270 degrees Celsius or minus 454 degrees Fahrenheit).

Koh points out three particular missions that could be the key to uncovering the distant, faint signals of the first stars. “LIGO [the Laser Interferometer Gravitational-Wave Observatory] can detect more stellar-mass, or greater black hole mergers. With a large enough population sample we can make some statistical models of how many can be attributed to Population III black holes,” Koh explains.

“The SKA [Square Kilometre Array] will be the best tool for looking into the early universe, because the universe was full of neutral hydrogen then, and the SKA can detect neutral hydrogen,” he continues. The SKA will be the world's largest radio telescope when it is finished and science operations begin in the 2020s, with it co-hosted in Australia and South Africa. This will allow astronomers to study the CMB in unprecedented detail, largely surpassing the power of the EDGES project.

“The JWST [James Webb Space Telescope] can detect more infrared, which is further back into the early universe. It is still unlikely to directly observe individual Population III stars, since they are very faint and very far, but we could get lucky and find a particularly bright Population III galaxy. It certainly will detect more Population II galaxies, which will further constrain Population III models,” Koh concludes.

“JWST can detect more infrared, which is further back into the early universe” **Dr Daegene Koh**



© NASA

Above: Daegene Koh works at the Kavli Institute for Particle Astrophysics and Cosmology at Stanford

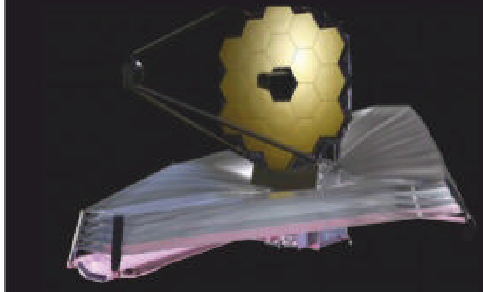
Right: When Population III stars went supernova, they introduced the universe to its first metals

The future Population III hunters

Astronomers hope to delve deeper back in time to find these ancient stellar behemoths

James Webb Space Telescope (JWST)

NASA's successor to Hubble will have a greater light-collecting capability in a new wavelength, infrared. Infrared has a longer wavelength than visible light, meaning the expansion of the universe stretches light to infrared, known as 'redshift'.



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Square Kilometre Array (SKA)

This radio telescope project will be situated in both South Africa and Australia and will have a sensitivity 100-times greater than any radio telescope currently in use. This will allow astronomers to pierce through the reionisation era and have a look around the Dark Ages for signs of a cosmic dawn.

©SKA Organisation

Laser Interferometer Gravitational-Wave Observatory (LIGO)

LIGO has already had much success in observing the merger of black holes and neutron stars, so hopefully this form continues and astronomers can use it to detect the merger of enormous black holes that are remnants of Population III stars.

©Caltech/MIT/LIGO Lab

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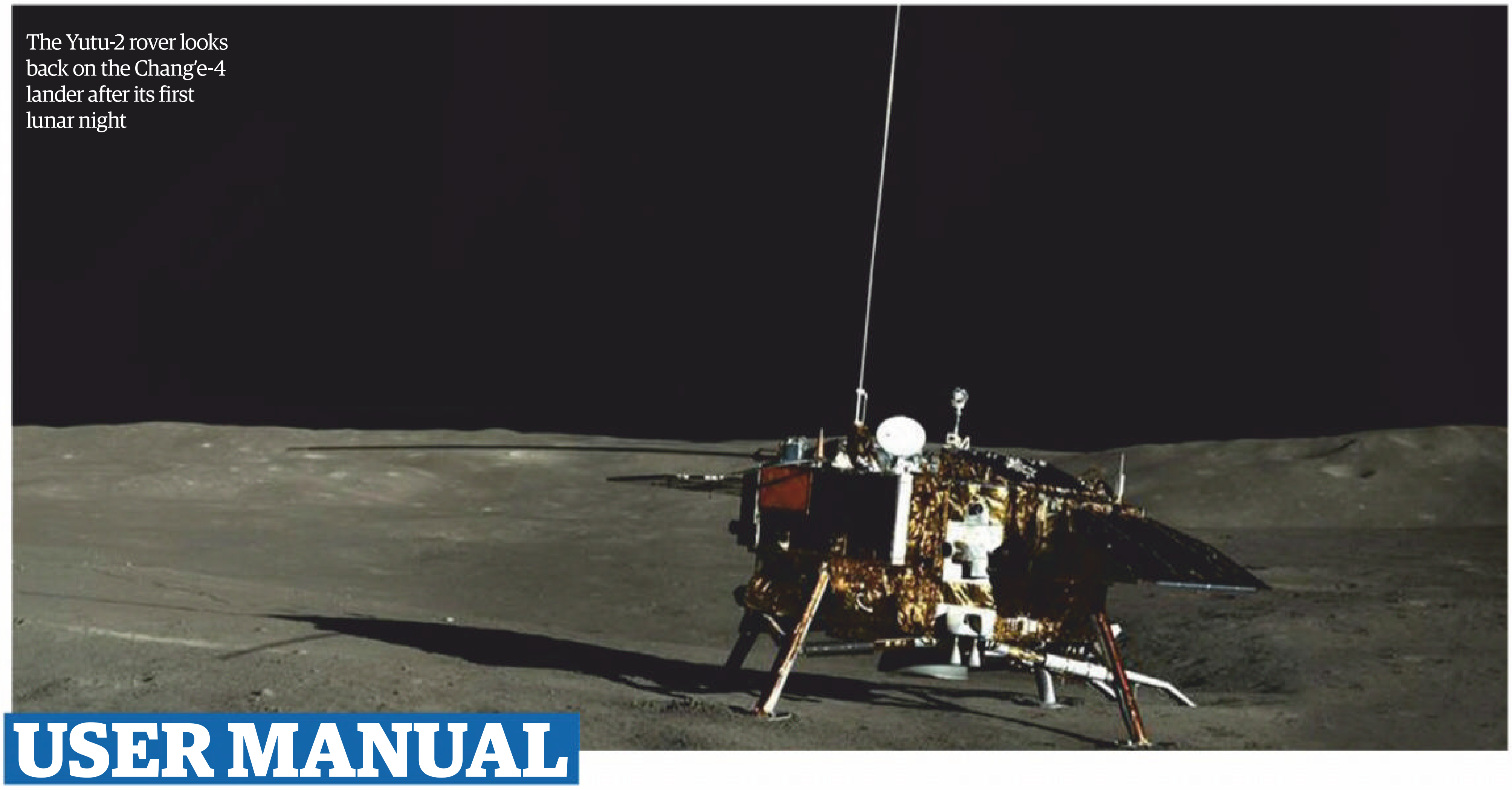


The Yutu-2 rover looks back on the Chang'e-4 lander after its first lunar night

© Xinhua/China National Space Administration

USER MANUAL

Chang'e-4

China's second lunar lander is the first to explore the far side of the Moon, a face not seen by us on Earth

THE SPECS

Launch: 7 December 2018

Mission type: Lunar lander and rover

Launch vehicle: Long March 3B

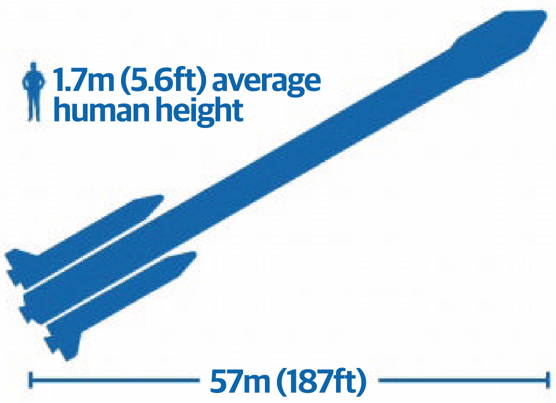
Target: The Moon

Operator: China National Space Administration (CNSA)

Launch site: Xichang Satellite Launch Center

Launch mass: 1,340 kilograms (3,000 pounds)

Components: Lander, rover and relay satellite



Chang'e-4 is the fourth instalment in the Chinese Lunar Exploration Program and the second Chinese lander/rover mission to visit the Moon. Many space organisations name missions after gods and goddesses - NASA's Juno mission, for example - and the China National Space Administration (CNSA) has done this in naming its Chang'e missions, aptly named after the Chinese goddess of the Moon.

Chang'e-4 is similar to its predecessor Chang'e-3 in that it will place a lander on the lunar surface before releasing a rover, Yutu-2. The main difference between the two is that Chang'e-4 will explore where no man or machine has ever explored before.

On 3 January 2019 Chang'e-4 made a soft landing in the Von Kármán crater in the South Pole-Aitken basin, an immense impact crater in itself and also one of the largest and oldest basins on the Moon. This crater is situated on the far side of the Moon, a side of the Moon people on Earth have only seen in images taken by and from spacecraft. Because the Moon is tidally locked to Earth we see the same face every night, one covered in dark seas of basaltic plains, also known as 'mares'. But on the far side these plains are scarce, it peppered with many more impact craters. Recent analysis of the lunar south pole has also revealed the presence of lunar water, an extremely exciting prospect for future human space exploration and the scientific understanding of how our Earth-Moon system evolved.

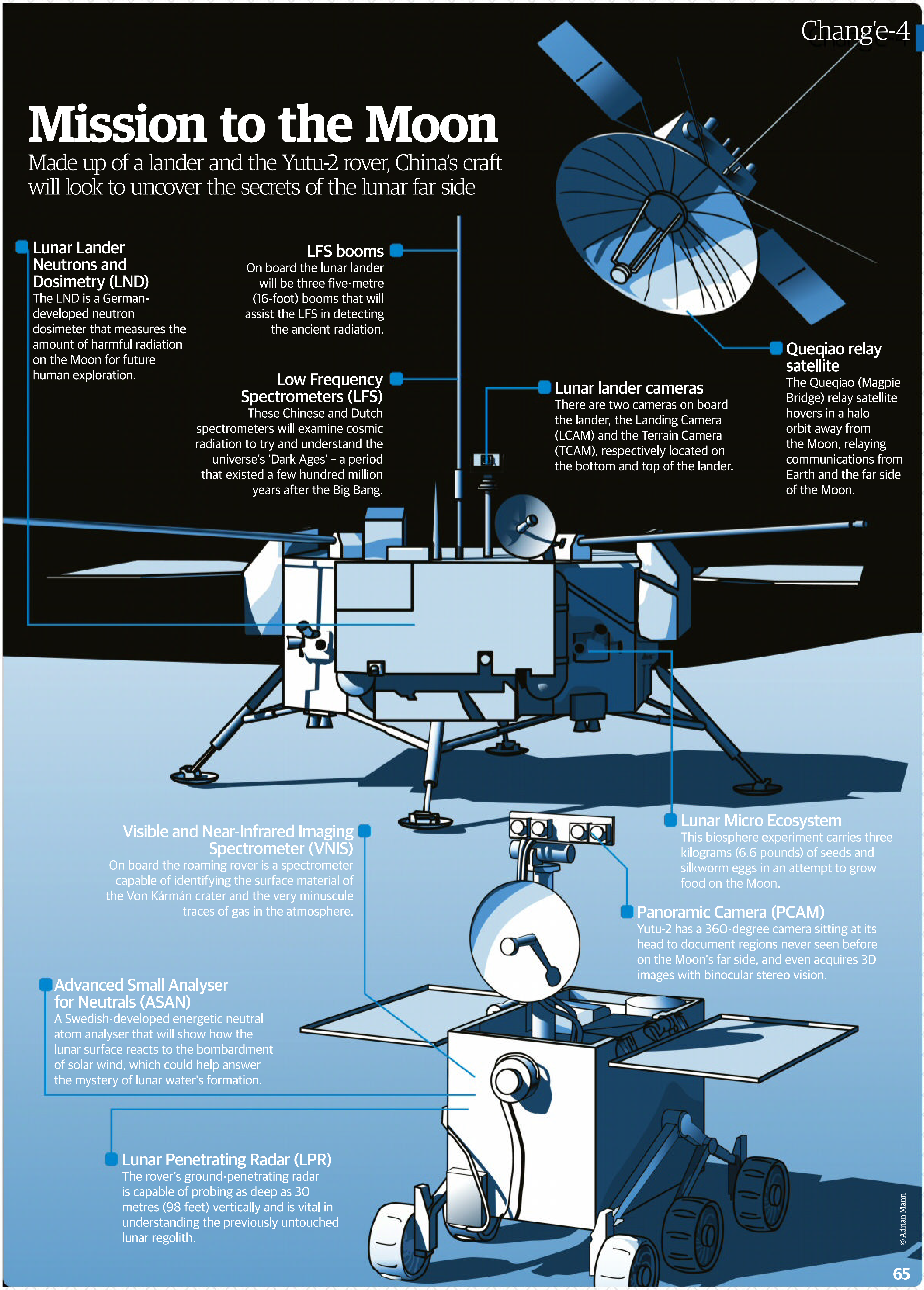
Tantalising thoughts of what could reside in this untouched region - which could answer questions about our Moon that have lingered for generations - are what have driven astronomers and engineers to land Chang'e-4 there. In order to perform a proper analysis of the area the Chang'e-4 team partnered with institutions and universities from Germany, the Netherlands and Sweden. They provided the lander and the Yutu-2 rover with the spectroscopes, cameras, neutral atom analysers and dosimeters needed to run its unique experiments.

On 7 December 2018 the Chang'e-4 mission was launched from Xichang Satellite Launch Center in Sichuan Province on the tip of a Long March 3B rocket. Since touchdown the Chang'e-4 lander and its companion, the Yutu-2 rover, have enjoyed much success and adventure, well surpassing their lifetime design of three months. After the initial victory of the landing, more excitement came when

> "Recent analysis of the lunar south pole has also revealed the presence of lunar water, an extremely exciting prospect"

Mission to the Moon

Made up of a lander and the Yutu-2 rover, China's craft will look to uncover the secrets of the lunar far side



Lunar Lander Neutrons and Dosimetry (LND)
The LND is a German-developed neutron dosimeter that measures the amount of harmful radiation on the Moon for future human exploration.

LFS booms
On board the lunar lander will be three five-metre (16-foot) booms that will assist the LFS in detecting the ancient radiation.

Low Frequency Spectrometers (LFS)
These Chinese and Dutch spectrometers will examine cosmic radiation to try and understand the universe's 'Dark Ages' – a period that existed a few hundred million years after the Big Bang.

Lunar lander cameras
There are two cameras on board the lander, the Landing Camera (LCAM) and the Terrain Camera (TCAM), respectively located on the bottom and top of the lander.

Queqiao relay satellite
The Queqiao (Magpie Bridge) relay satellite hovers in a halo orbit away from the Moon, relaying communications from Earth and the far side of the Moon.

Visible and Near-Infrared Imaging Spectrometer (VNIS)
On board the roaming rover is a spectrometer capable of identifying the surface material of the Von Kármán crater and the very minuscule traces of gas in the atmosphere.

Lunar Micro Ecosystem
This biosphere experiment carries three kilograms (6.6 pounds) of seeds and silkworm eggs in an attempt to grow food on the Moon.

Panoramic Camera (PCAM)
Yutu-2 has a 360-degree camera sitting at its head to document regions never seen before on the Moon's far side, and even acquires 3D images with binocular stereo vision.

Advanced Small Analyser for Neutrals (ASAN)
A Swedish-developed energetic neutral atom analyser that will show how the lunar surface reacts to the bombardment of solar wind, which could help answer the mystery of lunar water's formation.

Lunar Penetrating Radar (LPR)
The rover's ground-penetrating radar is capable of probing as deep as 30 metres (98 feet) vertically and is vital in understanding the previously untouched lunar regolith.

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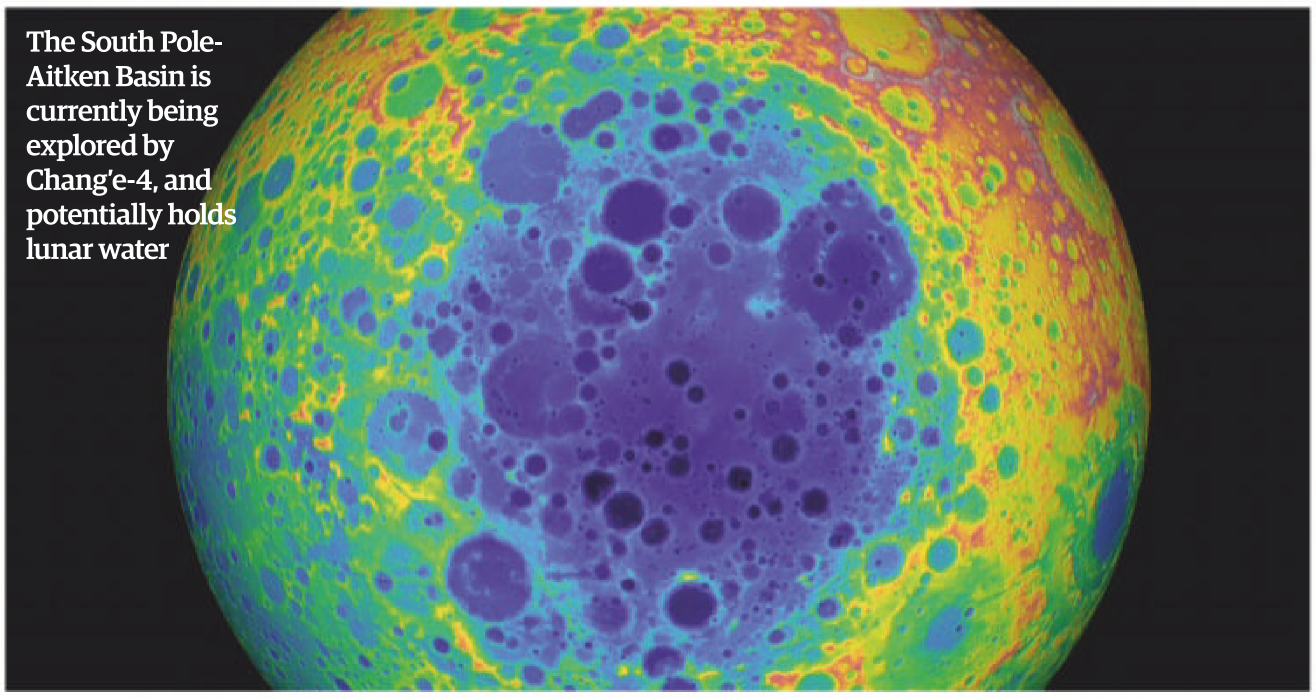

The South Pole-Aitken Basin is currently being explored by Chang'e-4, and potentially holds lunar water

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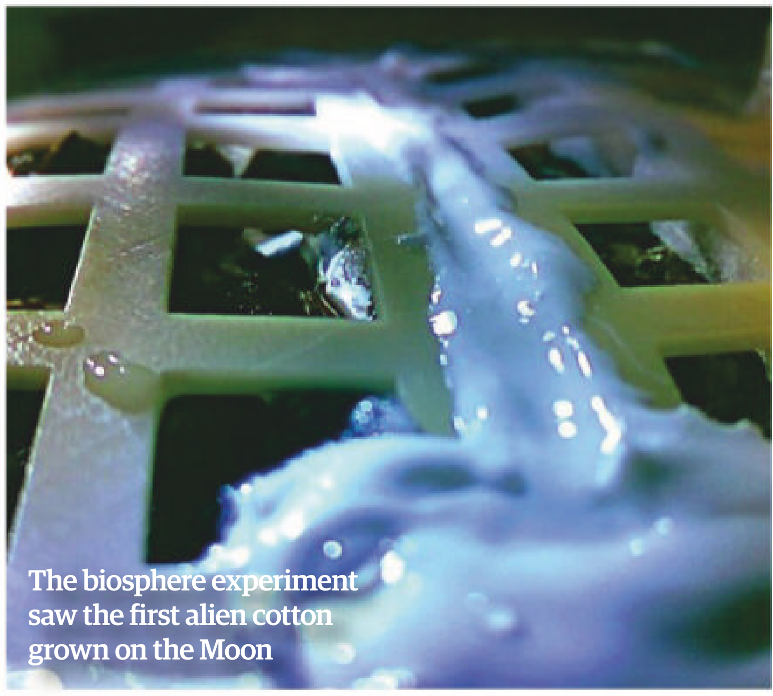
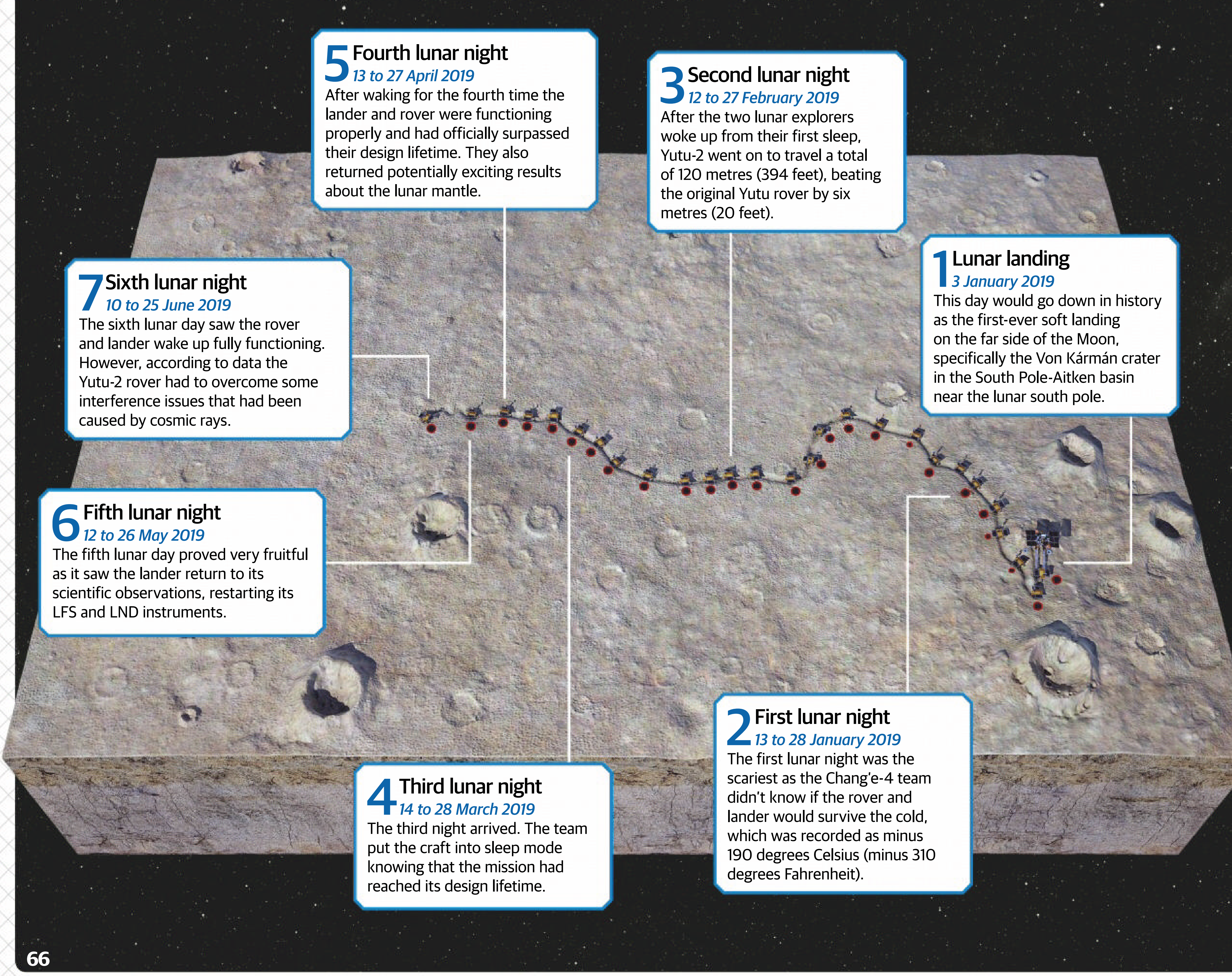


The biosphere experiment saw the first alien cotton grown on the Moon

© Xinhau

Yutu-2's lunar route



1 Lunar landing

3 January 2019

This day would go down in history as the first-ever soft landing on the far side of the Moon, specifically the Von Kármán crater in the South Pole-Aitken basin near the lunar south pole.

2 First lunar night

13 to 28 January 2019

The first lunar night was the scariest as the Chang'e-4 team didn't know if the rover and lander would survive the cold, which was recorded as minus 190 degrees Celsius (minus 310 degrees Fahrenheit).

3 Second lunar night

12 to 27 February 2019

After the two lunar explorers woke up from their first sleep, Yutu-2 went on to travel a total of 120 metres (394 feet), beating the original Yutu rover by six metres (20 feet).

4 Third lunar night

14 to 28 March 2019

The third night arrived. The team put the craft into sleep mode knowing that the mission had reached its design lifetime.

5 Fourth lunar night

13 to 27 April 2019

After waking for the fourth time the lander and rover were functioning properly and had officially surpassed their design lifetime. They also returned potentially exciting results about the lunar mantle.

6 Fifth lunar night

12 to 26 May 2019

The fifth lunar day proved very fruitful as it saw the lander return to its scientific observations, restarting its LFS and LND instruments.

7 Sixth lunar night

10 to 25 June 2019

The sixth lunar day saw the rover and lander wake up fully functioning. However, according to data the Yutu-2 rover had to overcome some interference issues that had been caused by cosmic rays.

the lander's biosphere experiment began showing interesting signs of life as the cotton seeds in the experiment began to sprout - making the first lunar vegetation. Alien crops aside, the lander and rover continued to gain plenty of scientific data thanks to their instruments - created from international collaboration - and the continued support of the Queqiao relay satellite.

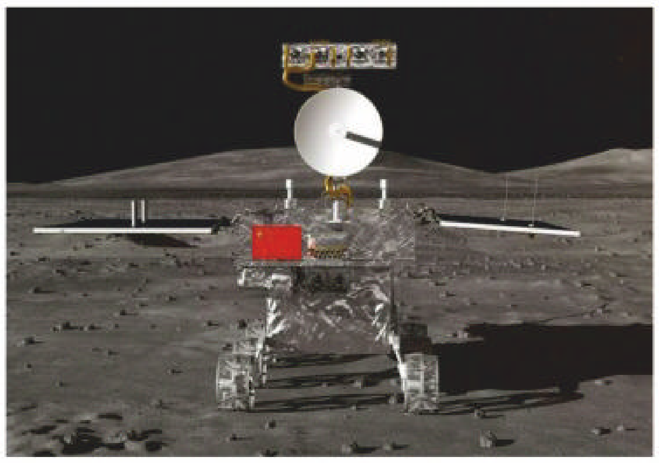
The first real test for the duo came on the first 'lunar night' - as a lunar day equates to two Earth weeks, as does the night. The main challenge during this long night is the cold: with the Sun out of the picture it can reach freezing temperatures that cause danger to the electronics or the mechanics of a craft. The Chang'e-4 team packed up the solar panels and entered into sleep mode, where the craft hibernated for a lunar night. After the night was over the two woke up reporting no issues, and this has been ongoing for the last lunar week at the time of writing.

In terms of scientific discovery there hasn't been much to rave about other than the alien crops, which unfortunately did not survive the first lunar night. However, there has been recent evidence found by Yutu-2's spectrometers that the impact that created the Von Kármán crater churned up material deep within the Moon's ancient mantle. Li Chunlai, a professor of the National Astronomical Observatories of China at the Chinese Academy of Sciences (NAOC), explains: "Understanding the composition of the lunar mantle is critical for testing whether a magma ocean ever existed, as postulated. It also helps advance our understanding of the thermal and magmatic evolution of the Moon."

TOP TECH

Yutu-2 rover

The Yutu-2 rover, the successor to Chang'e-3's Yutu rover, is very similar in size, with dimensions about 1.5 metres (five feet) long and one metre (three feet) wide and tall, but it is equipped with a 360-degree panoramic camera, the Lunar Penetrating Radar, the Visible and Near-Infrared Imaging Spectrometer and the Advanced Small Analyser for Neutrals. Since its release from the lander it has gone on to travel over 270 metres (886 feet) at the time of writing, and looks like it won't stop there, having already surpassed the original Yutu's 115 metres (377 feet) of travel.



© Xinhau

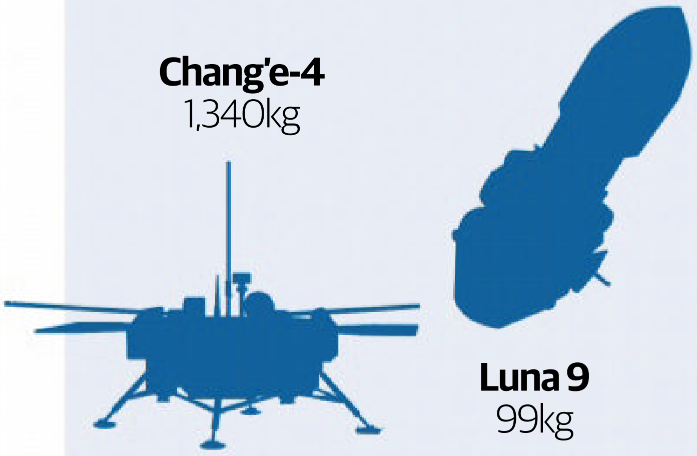
During lunar day eight, the Yutu-2 covered a distance of roughly 33 metres (108 feet)

Head-to-head

Chang'e-4 vs Luna 9

The Soviet Union's Luna 9 made the first soft landing on the Moon by an unmanned space probe in 1966. Where the Soviet's space probe had a landing mass of close to 100 kilograms (220 pounds), Chang'e-4 - both with its lander and rover - was close to 1,350 kilograms (3,000 pounds). This weight makes the soft landing all the more impressive.

Luna 9 landed in Oceanus Procellarum, taking pictures and sending back footage for about three days; Chang'e-4 has been operating for over three months, and has conducted multiple experiments as well as taking images. This is a testament to how far space probes have come in the last 50 years!



Vital statistics

270 metres *(886 feet)* = The distance Yutu-2 has travelled so far.

65,000 kilometres *(40,000 miles)*
The distance between the Moon and the Queqiao relay satellite.

5 = The number of scientific instruments on the lander and rover, not including cameras.

2,500 kilometres *(1,600 miles)*
The diameter of the South Pole-Aitken basin.

-190 Celsius *(-310 Fahrenheit)* = How cold a lunar night can get.

FUTURE MISSIONS

How to land on the far side of the Moon

1 Launching the probes

The Chang'e-4 lander, with its Yutu-2 rover sheltered within, was launched from Xichang Satellite Launch Center on 7 December 2018. Prior to that, the Queqiao relay satellite was launched on 20 May 2018.

© Xinhau

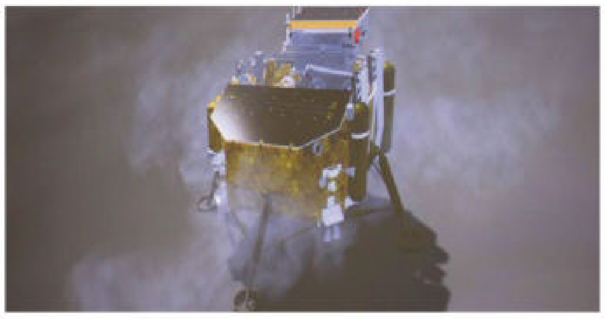
2 The long ride ahead

After almost five days of travelling through space, the Chang'e-4 spacecraft finally arrived at the Moon and fired its onboard jets to enter a safe and secure lunar orbit, preparing to eventually land.

© NASA

3 Gradual decline

Chang'e-4 was gently lowered over the coming days until its perilune - its closest point to the Moon's surface - was just 15 kilometres (nine miles). It prepared for its soft landing on the Moon on 30 December 2018.



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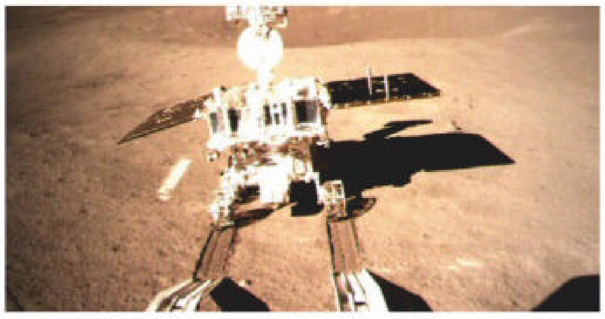
4 Off to explore

A few days after the landing on 3 January 2019, the Yutu-2 rover was let loose and began its journey around the crater. The rover travels across the Moon during the lunar days, as the nighttime is far too cold for it to operate.



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BREXIT

WHAT IT MEANS FOR ASTRONOMY AND SPACE EXPLORATION

Space agencies reveal how the UK's efforts will be impacted by the decision to leave the European Union

Professor Richard Massey is on a beach, enjoying a short break from his role of Royal Society Research Fellow at the Institute for Computational Cosmology at Durham University. **All About Space** interrupts him with a question about Brexit and he immediately drops everything. "I feel strongly about this issue," he tells us, before launching into a passionate take on a subject that has split the United Kingdom down the middle.

There is no getting away from Brexit - the UK's departure from the European Union (EU) which, at the time of writing, has been set for 31 October - but we know that it will inevitably affect the UK, Europe and the wider world in some way, whether good or bad.

The impact will be felt in space, too: the UK's efforts in space exploration, astronomy and astrophysics depend to a great extent on global co-operation, and since the UK's interests are very much intertwined with that of Europe there's a good chance contracts will be jeopardised.

"Brexit has already been a disaster for British science," argues Massey. "Scientific research is a long-term activity, and the uncertainty of not knowing whether we will be eligible to be part of big research projects over the next few years means that it has been easiest to simply leave out British scientists from collaborations that are being set up now."

British scientists say they began to suffer a backlash shortly after the results of the referendum on 23 June 2016, when 51.89 per cent of the country voted to leave the EU and 48.11 per cent voted to remain. The following month *The Guardian* surveyed the UK's Russell Group universities - which include Oxford, Cambridge and 22 others - and there was early talk of UK applicants having been dropped from EU bids.

By then the former science minister Jo Johnson had already raised concerns over potential discrimination against UK scientists, but the situation hasn't improved. The EU pumped €79 billion into Horizon 2020, Europe's largest ever funding programme for research and innovation, allowing UK institutions to apply for European Research Council (ERC) grants. But under a no-deal

Brexit the funding line would be cut, and since the UK won 22 per cent of ERC awards in the decade to 2016, the drop would run into the hundreds of millions each year.

To make up for this the UK has considered creating a post-Brexit international research fund on the understanding that the country would also lack full access to Horizon 2020's successor, Horizon Europe, which starts in 2021. Participation rules for non-EU nations are the subject of continuing talks, yet British cosmologist and astrophysicist Martin Rees tells **All About Space** that the impact will be felt regardless.

"There would, of course, be a loss of funding in this situation, but that in itself is not as bad as the other spin-offs," he says. "The ERC is not only a source of funds, its awards have high prestige because it is deemed to have better assessment processes than our own research councils." The knock-on effects, he argues, will be huge.

"The main downside is simply that science is an enterprise that is especially international and collaborative," he continues. "The UK has traditionally been 'welcoming', and its scientific strength benefits hugely from the participation of EU citizens. But the EU citizens with long-term posts in my institute say they wouldn't have come on the present or likely terms, and even if visas are available for highly skilled people, they are only willing to settle if they know there is freedom of movement for families."

It is certainly true that scientific advances are created by people with specialised but complementary knowledge working together. "The different jigsaw pieces match up and solve an unexpected puzzle," Massey says. "In recent years the UK has made the most connections with other EU countries, and trans-European science has become efficient because of our close links."

"Research and innovation is one of our national strengths" **Prof Richard Massey**

There is a case study pointing to the UK's fate should there be a no-deal Brexit. Switzerland was able to access Horizon 2020 even though it's not an EU member, but it was temporarily exiled from the research programme in a dispute over immigration between 2014 and 2016. Its funding, reputation and standing slumped, with the number of projects led by Swiss researchers falling. The country was left on the outside looking in.

Could the same happen in the UK? "It's a huge pity because research and innovation is one of our national strengths," Massey says. "We win far more money in peer-reviewed research grants than we send to the EU, and it is this European money that keeps the UK at the forefront of medical, STEM and space research."

Any deal struck with the EU would, it seems, need to take such things into account, knowing the European Commission has big plans for science. "It has ambitions to spend €100 billion on science in its next funding period, and much of that involves space," says Andrew Shepherd, professor of Earth observation at the University of Leeds. "This includes spending a further €16 billion in the Copernicus satellite programme. If our commercial and educational space science communities are excluded from future EU programmes, that will be a major blow to our industrial growth strategy. A deal with the EU makes sound financial sense; no deal does not."

There are some chinks of light, however. Even in the case of no deal being struck the UK will remain a part of the European Space Agency (ESA), since it is separate to the EU. It means any projects driven by the ESA will, on the face of it at least, have no effect on the co-operation between UK and European universities and researchers. "But if it's a project driven by EU funds, you might get problems," argues Dr Bleddyn Bowen, lecturer in international relations at the University of Leicester. "There are no clear answers, though, as with many things with Brexit."

Bowen points to the impact that's already been felt. The UK lost access to Galileo, Europe's answer to GPS, thanks to a disagreement over encrypted signals called the Public Regulated Service. It cannot currently bid for contracts in other EU-funded space projects such as GovSatCom either, which is pooling member states' secure satellite communications.

Bidding for contracts in the Copernicus Earth observation programme has also become more complex, and it's set to rely on workarounds in the event of no deal. As for the EU Space Surveillance

The ESA has an annual budget of €5.72 billion, with a sizeable chunk now coming from the EU as the two bodies tie more closely together – will this alter the UK's relationship?

© ESA

and Tracking programme, the government clearly states "the UK will not be eligible to participate if there's a no-deal Brexit", although the country will continue to receive space, surveillance and tracking data from the US.

One big issue is that the ESA and the EU are aligning more and more as the years go by. Today the EU is the largest contributor to the agency's budget, putting €1.25 billion towards the €5.72 billion it receives each year. "If the ESA implements EU-funded projects, countries like the UK, Switzerland and Norway won't have an automatic right to bid for the contracts," Bowen tells us. This could have an impact on UK astronomers and astrophysicists working in the EU. "The EU can make unilateral rules and regulations on how lenient they want to be towards UK citizens in specific industries based on whether there are certain skills that say they want. The EU can make specific immigration policies based on nationality as long as the EU 27 agrees to it.

"But the biggest problem with a no-deal is the more mundane aspects of the transport of people and goods every day, because the European space industry is highly integrated. People and components of data must travel between the member states without any avoidable friction."

Putting up barriers would affect space manufacturers, since components used in creating spacecraft are often imported. Surrey Satellite Technology and Airbus are among the worried companies. The former's use of commercial off-the-shelf components reduced manufacturing costs, and being out of the Space Surveillance and Tracking programme has an impact on the £13 million RemoveDEBRIS project. It's little wonder companies are applying to come under the jurisdiction of EU regulators.

"Airbus remains concerned by a potential no-deal, and we continue to plan for that scenario as that is the only way any responsible business can plan," says Jeremy Close, spokesman for Airbus. "We have launched a major Brexit project in order to understand, eradicate and/or mitigate risks and we continue to look for further clarity, and the removal of uncertainty, as soon as possible. The shape of the future UK/EU relationship remains of critical importance for us."

Airbus continues to be a major industrial partner in Galileo, active in all segments - System, Space, Ground, Launchers and Ops - he says. Airbus also has 50 per cent of the work of the 22 FOC satellites: navigation payloads by SSTL, Solar Arrays by Dutch Space, payload electronics by Airbus DS and TESAT. "If the UK opts for its own satellite navigation system then Airbus' space operations in the UK have the skills and expertise to lead the development of it," Close adds.

So things aren't too bad? Astronomer Chris Leigh, who campaigned for Brexit, doesn't think so. "I think UK R&D will manage fine if we are excluded from future EU research programmes, but obviously there will be some individual projects who rely on Horizon 2020 funding and could need government support to complete their activities," he says.

He points out that EU programmes only support three per cent of UK research and development, and

Launching a new era for the UK

Graham Peters, chair of UKspace, the trade association of the UK space industry, talks about the potential impact of Brexit

How is the UK space industry approaching Brexit?

With a mixture of nervousness and optimism. Obviously the European Union is an important customer for British-based businesses because it is the owner and operator of Galileo and the observation system, Copernicus – programmes the UK is very heavily involved with. We are supportive of the government's position on the Withdrawal Agreement because it includes an intent for continued collaboration with the EU in space.

What if there is a no-deal?

I expect the government and EU would be looking to formulate agreements on specific areas on a case-by-case basis. Research and space could be one of those areas, as there are benefits to both sides. Obviously this would take additional time, and in a case where there was no agreement at all then we would be out of those programmes, which would be something that we would not welcome.

What cause is there to be optimistic?

A new dawn could be breaking. The prime minister has been very supportive of the space sector in his speeches. He said: "Let's get going now on our own position navigation and timing satellite and Earth observing systems – UK assets orbiting in space, with all the long-term strategic and commercial benefits for this country." That positive statement supports our sector and has been received well. It shows the government recognises the importance of the space sector to the UK economy – space systems underpin economic activity of around 15 per cent, or £300 billion pounds a year – to the environment, to our national security and our international partnerships. We are now more optimistic that the government will release the funding which will then allow it to follow through with the ambition, with Boris Johnson's ambition.

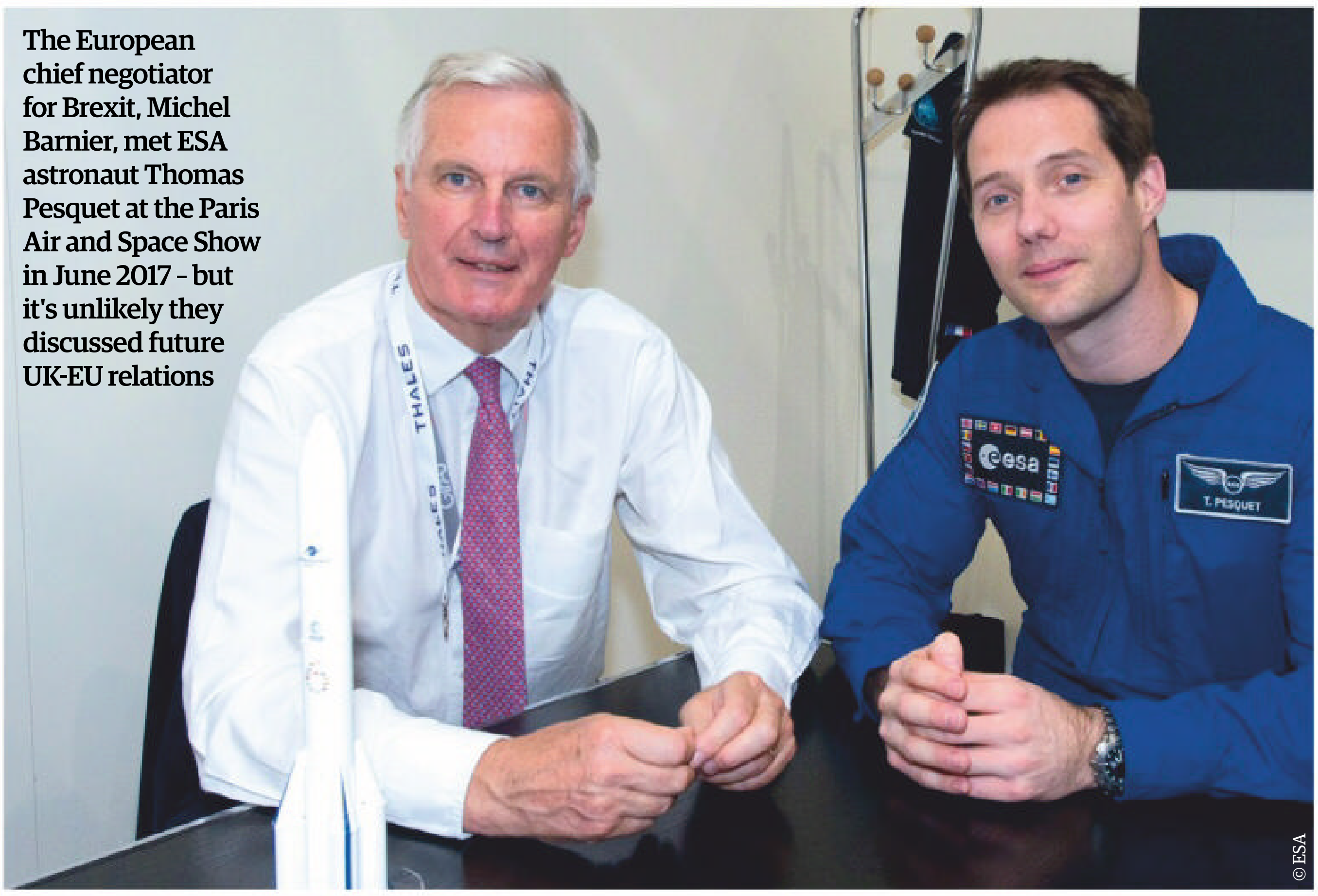
Do you worry that prestigious funding streams created by the EU may be cut off, such as Horizon 2020, for instance?

Space is more than just what goes on within the EU. We are going to continue as a member of the European Space Agency, which is not part of the EU, and collaborations with European partners will continue through the ESA. Yes, I imagine that the EU would like to take more of a leading role in space and space research in the long term, but at the moment the ESA is a key organisation, of which we were a founding member.

What are you pressing the government to do?

We're calling on the government to establish a national space innovation fund in addition to the navigation and Earth-observing systems I mentioned earlier. Many countries that we compete with around the world – for example the French and the Germans – have domestic space programmes with robust funding that are carried out nationally. This is in addition to the work they do with the ESA and with the EU.

We are calling on the government to invest around £150 million a year in a space innovation fund that will allow industry to co-fund big investments to unlock new opportunities, leverage the UK's fantastic scientific research base, attract new businesses into the UK and help grow the existing businesses here. This will help to continue to create that leadership that the UK has always had in this sector.



The European chief negotiator for Brexit, Michel Barnier, met ESA astronaut Thomas Pesquet at the Paris Air and Space Show in June 2017 – but it's unlikely they discussed future UK-EU relations

© ESA

How does the UK contribute to space affairs?

The country is involved with some key organisations and projects, here's how the situation could be affected once we leave the European Union

European Space Agency

MEMBERSHIP DETAILS

The European Space Agency (ESA) has 22 member states, 20 of which are in the EU and two of which are not – Norway and Switzerland. The UK's membership does not, therefore, depend on it remaining in the EU and, indeed, there are also two non-full members, Canada and Slovenia.

© ESA

FINANCE

Few other member states contribute as much financially as the UK, which hands over €369.6 million each year – a sum that amounts to 8.8 per cent of the ESA's costs, behind only France (28.1 per cent), Germany (22.2 per cent) and Italy (10.1 per cent).

NOTABLE RETURNS

The UK has seen ESA investment in the Harwell Space Cluster just outside Oxford, where 1,040 people are employed across 92 organisations – the UK Space Agency is based here along with RAL Space and the Satellite Applications Catapult. The return on UK investment is said to be £10 for every £1 we spend, not accounting for the payback in terms of space exploration and astronomy.

IMPACT ON RESEARCH

Research carried out with ESA money has also benefitted fields as diverse as Alzheimers and climate change. The ESA trained Tim Peake and sent him into space, inspiring millions of children and encouraging science in the UK.

AFFECTED? NO

The UK will remain a member of the European Space Agency.

Galileo

MEMBERSHIP DETAILS

The Galileo global navigation satellite system was created by the European Union, so the United Kingdom has been a part of that as a result. When Article 50 was invoked and Brexit negotiations began, the European commission began to block UK space industry involvement. The UK government later pulled out.

FINANCE

The UK invested £1.2 billion in Galileo, but it will not be putting any more money into the project, which is set to cost £9 billion overall. It is instead pledging £92 million towards a study of a potential alternative system with other countries, the cost of which may well reach £5 billion.

NOTABLE RETURNS

Since UK companies cannot be involved in the manufacturing of the security elements of the programme, the country will not see any returns on its investment. UK-based companies which were heavily involved in the system's development have been frozen out. Airbus managed the ground services, but a follow-up contact was lost.

IMPACT ON RESEARCH

The UK will not be granted privileged access to vital information about Galileo's encrypted Public Regulated Service – a military grade signal. Only EU member states, their armed forces, emergency services and government agencies will be privy to this component for reasons of security.

©Thilo Kranz/DLR

AFFECTED? YES

The UK has already pulled out of the Galileo programme and is seeking an alternative.

European Space Surveillance and Tracking

MEMBERSHIP DETAILS

A Space Surveillance and Tracking framework was set up in 2014 by the European Commission, and a year later a group of five EU states – France, Germany, Italy, Spain and the UK – formed an SST consortium which got together with the EU Satellite Centre to form European Space Surveillance and Tracking (EUSST). Poland, Portugal and Romania joined at the end of 2018.

©EUSST

FINANCE

The UK Space Agency hands out EU funding to UK organisations, and this allows them to participate in the programme. So far the cash has been used to create 11 radars, 19 telescopes and four laser stations. The UK Space Operations Centre is among four overseeing the results.

NOTABLE RETURNS

EUSST was created to monitor debris re-entering the atmosphere and to prevent satellites and other EU space infrastructure from colliding with orbital objects. This is vital given the number of assets that are now in space, and its remit extends to the detecting and characterisation of in-orbit fragmentations.

IMPACT ON RESEARCH

If the UK leaves the EU without a deal, grant funding for the country's science and technical groups will cease. Services received by UK satellite owners and operators may also be made unavailable, although the government says it is seeking clarification. The United States will, however, continue to send space, surveillance and tracking data to the UK.

AFFECTED? YES

The UK will not participate in the programme, preventing UK companies from contributing.

Copernicus Earth observation programme

MEMBERSHIP DETAILS

Copernicus is an Earth-monitoring programme dubbed 'Europe's eyes on Earth'. It is coordinated and managed by the European Commission in partnership with Member States, the ESA, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF), EU Agencies and Mercator Océan.

FINANCE

From 2014 until 2020, the EU is expected to have spent €4.3 billion on Copernicus. Through membership UK businesses, researchers and academics are able to bid for contracts that are tendered through the EU or through processes that use EU procurement laws. If there is a no-deal Brexit, this will not be allowed to continue.

NOTABLE RETURNS

Businesses which work to tackle environmental challenges reap the benefits of membership, which provides timely information about the effects of climate change while ensuring civil security. Copernicus draws upon the talents and work of some of the world's finest observation scientists and engineers – a large number of which are based in the UK.

IMPACT ON RESEARCH

Businesses, academics and researchers based in the UK will not be allowed to bid for future Copernicus contracts after Brexit via the EU. The UK will also lose access to data and information that is not available under a free and open data policy. Companies will, however, be able to bid for contracts via ECMWF, Mercator Océan and the ESA.

AFFECTED? YES

The UK will no longer participate, but there are workarounds for bidding organisations, with data also set to be made available via continuing UK membership of EUMETSAT, ECMWF and Mercator Océan.

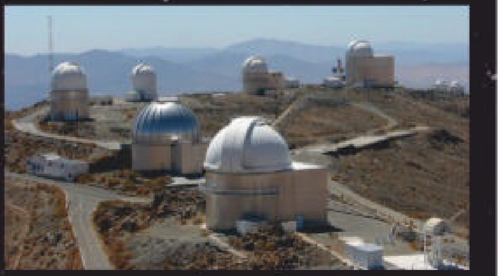
European Southern Observatory

MEMBERSHIP DETAILS

The UK joined the European Southern Observatory (ESO), an organisation dedicated to ground-based astronomy, in 2002 – nearly 40 years after it was created by Belgium, Germany, France, the Netherlands and Sweden in 1962. It is one of 16 member states, with the headquarters based in Germany and telescopes in Chile.

FINANCE

After an initial membership fee which cost in the region of £60 million, the UK has since handed over an annual subscription, which currently stands at approximately €26,640,000 – some 16.4 per cent of the ESO's revenue. The UK is a major financial contributor to the European Southern Observatory.



©ESO

NOTABLE RETURNS

From its observatories based in northern Chile, more than 730 staff – including 51 British nationals – operate some of the world's most advanced telescopes, with the Extremely Large Telescope currently under construction. The UK has wide expertise in millimetre- and submillimetre-wave astronomy, and British companies are involved in the Atacama Large Millimeter/submillimeter Array (ALMA).

IMPACT ON RESEARCH

Science has richly benefited. An international team led by Simon Driver at the University of St Andrews studied more than 200,000 galaxies and charted the slow death of the universe, for example. The Very Large Telescope was used by Leigh Fletcher at the University of Leicester to obtain infrared images of Jupiter. University teams in Cambridge, Warwick, Hertfordshire, London and Belfast are among those using facilities.

AFFECTED? NO

The UK will remain a member of the European Southern Observatory.

he believes it would be relatively straightforward to boost funding to existing UK funding councils to offset any shortfall.

"It might be that the ERC uses its semi-independence to include UK researchers in Tier 1 projects," he says. "When Switzerland was last in the EU's bad books, the ERC still included Swiss researchers as full members. However, this would require a limited association agreement with the ERC, and it would be uncertain how the EU would react. There is certainly a willingness among EU researchers to continue EU-UK collaboration, and also a frustration that the EU commission have politicised science to the degree they have."

The UK would also remain a part of many intergovernmental European science projects that are outside the EU's remit, including the ESA, as we've mentioned, as well as CERN (the European Organisation for Nuclear Research), the European Southern Observatory (ESO) and the European Molecular Biology Laboratory. "We could boost our funding to make a strong gesture and ensure additional routes to important collaboration," Leigh says.

With a fast-track research visa system to ensure mobility for scientists around the world, he is confident UK science can weather a Brexit on World Trade Organisation rules. Indeed, the UK government is looking to put £150 million into in-space robotics, low-cost access to space, satellite construction and rocket testing. It is also looking to launch satellites from Space Hub Sutherland, a proposed spaceport in the Scottish highlands, with backing from the UK Space Agency.

Whatever happens, most are in agreement that Brexit will go ahead in some form. "They're not going to take it off the table, and I think we'll end up with some form of Theresa May's Withdrawal Agreement," says Bowen. "It's fudge, but everyone can live with fudge."

Where are we heading?

No one knows for certain how Brexit will affect astronomy and space exploration in the long term – it depends on the chosen path

Brexit

Brexit is the United Kingdom's withdrawal from the European Union. There are three main possible outcomes.

Deal

Former Prime Minister Theresa May negotiated a Withdrawal Agreement which set out how the UK would leave the European Union. It was knocked back multiple times by Parliament, but a revised version could be put forward.

Continued contracts

If an agreement allows the UK to have access to multiannual financial framework procurements, then UK companies involved in the space sector should remain able to bid for EU space projects.

Space involvement

Having already withdrawn itself from the Galileo programme, the UK is likely to want to remain involved with other key projects, including Copernicus and GovSatCom.

Ongoing funding

It is likely that a deal would continue to allow the UK access to Horizon 2020 funding and that of its successor.

No deal

There is a chance that no agreement will be made with the European Union, leaving the UK to crash out. This could be due to the EU being unwilling to renegotiate the Withdrawal Agreement or Parliament rejecting any amends.

Space programmes

As well as ensuring the UK will never rejoin the Galileo programme, the UK's participation in Copernicus and Space Surveillance and Tracking will end, although the UK will receive some data.

European Space Agency

The UK's membership of the European Space Agency will continue since it is not part of the EU – that is, unless the EU's ever-closer ties with the ESA makes such membership untenable.

Alternative plans

A national alternative to the EU's Galileo satellite system will be sought, but there is no planned replacement for Copernicus nor any equivalent of the Space Surveillance and Tracking programme.

Stop-gap funding

The government has pledged to guarantee funding for successful competitive UK bids to Horizon 2020 for the lifetime of the projects. Future bids will not be possible once the UK leaves, however.

Drop in contracts

Any space contracts that would be awarded by the EU will not be granted to the UK. More UK companies may move to a member state, and jobs are likely to be lost.

Remain

Although an extension to Article 50 – the legal mechanism for leaving the EU which was triggered on 29 March 2017 – is entirely possible, it only kicks the can down the road. Revoking Article 50, whether through the will of MPs or a second referendum, would ensure the UK can remain in the European Union.

Welcomed back

The UK space industry will be able to continue as it does today. Universities and researchers will continue to ask for and receive EU funding and companies such as Airbus will be able to go for contracts.

Time delays

A number of contracts that would have gone to the UK have already been awarded within the EU, so unless those agreements are torn up, which is unlikely, it would still take some time for the UK to get itself back into a healthy position.

ASK Space

Our experts answer your questions

The two lobes of Ultima Thule were once two separate objects

© Nicholas Forder

Did you know?

Comet 67P/Churyumov-Gerasimenko, visited by the ESA's Rosetta probe and Philae lander in 2014, also has a bilobal shape.

SOLAR SYSTEM

How do 'bi-lobe' features form?

In the case of Ultima Thule, you can see from the imagery that this is the result of two distinct objects that formed independently and came to be resting on one another. They underwent a very gentle merger and now they're in contact.

In the case of comets, we really don't know that this is a primordial signature because the comets we have observed have evolved and been affected by being near the Sun. It's quite likely their shapes and other properties have been very heavily affected by that, as computer models have shown.

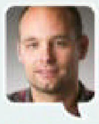
Alan Stern is a planetary scientist at the Southwest Research Institute and the principal investigator of NASA's New Horizons mission

ASTROPHYSICS

Can colliding neutron stars produce gravitational waves?

All neutron star mergers produce gravitational waves; this is something the astronomical community is extremely confident about. The reason for this confidence is that, when it comes to predictions of gravitational waves, mergers of neutron stars and of black holes are extremely straightforward exercises in general relativity, although the actual calculations are time-consuming for practical reasons. What matters for us is whether these mergers occur sufficiently close to detect with gravitational wave detectors.

The breakthrough detection of gravitational waves from two merging neutron stars - gamma-ray burst GRB 170817, and gravitational waves GW170817, both labelled after the date of detection - came with a whole slew of bonus features. The gravitational waves were followed within seconds by a brief pulse of gamma rays - a gamma-ray burst - which we understand to be generated by the launching of a narrow jet of gas moving at near-light speed.



Hendrik van Eerten is lecturer on computational astrophysics at the University of Bath

When two neutron stars collide, they release a tremendous amount of energy in the form of a kilonova

©ESO

"Mergers of neutron stars and of black holes are extremely straightforward exercises in general relativity"

Sub-Neptune planets are smaller than Neptune, but larger than Earth

©NASA

EXOPLANETS

How common are sub-Neptune exoplanets in the Milky Way?

They're pretty common. One really fantastic result from NASA's Kepler Space Telescope was that these small planets - and when I say small, I arbitrarily mean smaller than Neptune - tend to be very common in the Milky Way, at least out to periods that we have been able to probe, so about 50 days. In that sense a planet such as the size of this one is not very uncommon.

A really nice thing is that these exoplanets are really close to us and we can study them, but we know that they're pretty common thanks to Kepler, and we're waiting for one that is close enough that we can actually learn a bit more about it.

Diana Dragomir is a Hubble fellow at the Massachusetts Institute of Technology's Kavli Institute for Astrophysics and Space Research

ASK Space

Our experts answer your questions

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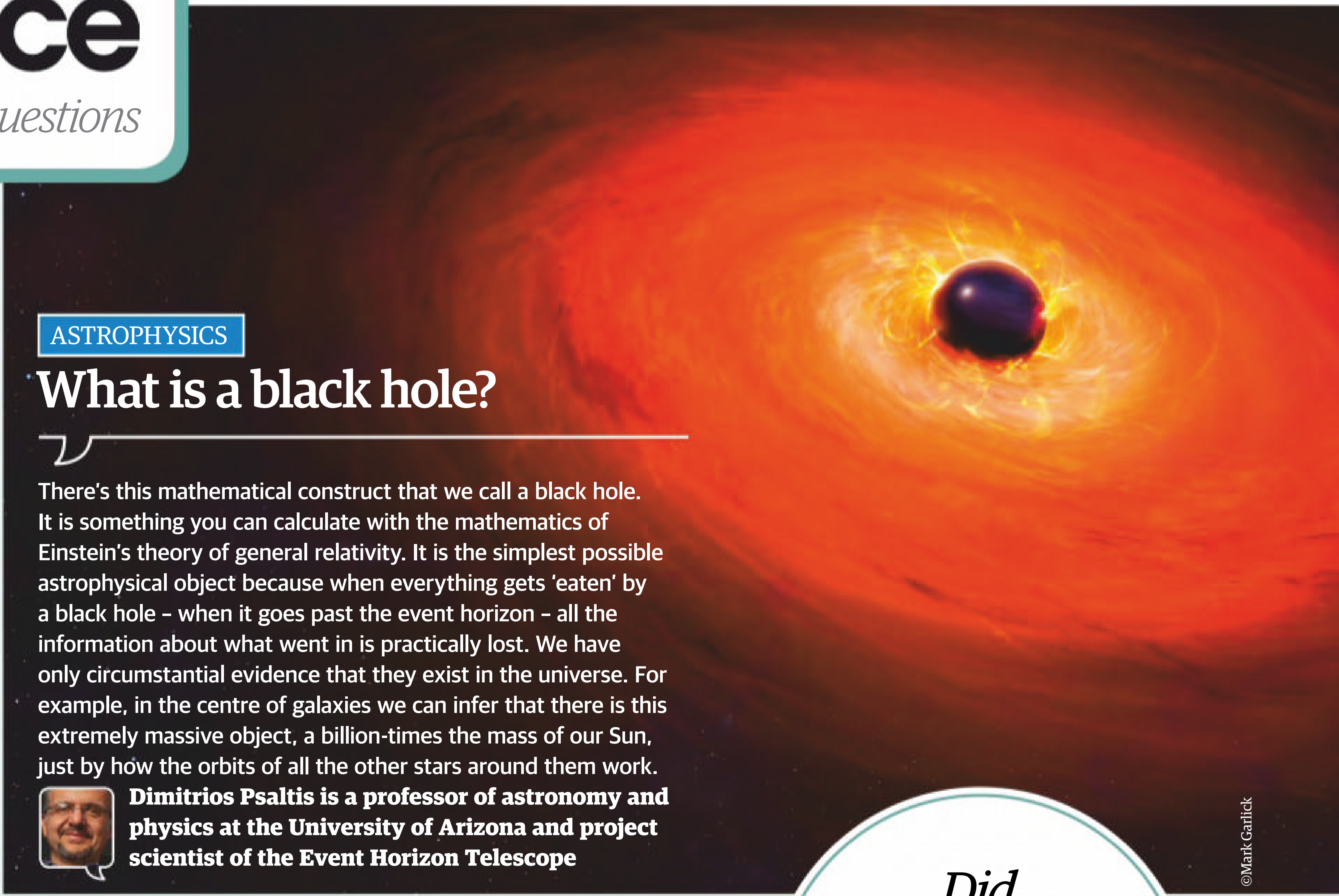

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ASTROPHYSICS

What is a black hole?

There's this mathematical construct that we call a black hole. It is something you can calculate with the mathematics of Einstein's theory of general relativity. It is the simplest possible astrophysical object because when everything gets 'eaten' by a black hole – when it goes past the event horizon – all the information about what went in is practically lost. We have only circumstantial evidence that they exist in the universe. For example, in the centre of galaxies we can infer that there is this extremely massive object, a billion-times the mass of our Sun, just by how the orbits of all the other stars around them work.

Dimitrios Psaltis is a professor of astronomy and physics at the University of Arizona and project scientist of the Event Horizon Telescope

HUNT FOR LIFE

Do you think we are alone in the universe?

I don't have a prejudice that we are alone because a quarter of all the stars in the universe have a planet in the habitable zone – where liquid water can exist on the surface – and the chemistry of life as we know it may be happening elsewhere. So why should we be so arrogant as to say that we are the only civilisation out there?

I think out of modesty, just modesty, we should all think we are not alone and then search. I'm not saying that we have any conclusive evidence at the moment, but we should just search for it and not have a prejudice against it.

Abraham "Avi" Loeb is an astrophysicist and the Frank B. Baird Jr. professor of science at Harvard University

> "We should all think we are not alone and then search"

Did you know?

The Event Horizon Telescope is a global network of telescopes stretching across Europe, North and South America and even Antarctica.

SOLAR SYSTEM

What will happen to the Solar System when the Sun reaches the end of its life?

When the Sun dies it will become a white dwarf as the fuel that has powered it for billions of years is depleted. In the process, which involves the Sun first becoming a giant branch star in about 5 billion years time, the Sun will engulf Mercury and Venus - just falling short of Earth. Mars, Jupiter, Saturn, Uranus and Neptune will all survive, and the fate of the Earth is unclear.

However, it is clear that Earth would have moved out of the Sun's habitable zone - the region where water exists as a liquid - and get too close to the Sun, meaning liquid water would just evaporate. This process will take about 5 million years. The asteroid belt will likely be destroyed by rotational spin-up due to the Sun's increased luminosity on its giant branch stellar evolutionary phase.

Dimitri Veras is an astrophysicist at the University of Warwick who specialises in planetary systems

The Sun won't turn into a red giant for another 5 billion years

©Tobias Roetsch

SPACE EXPLORATION

What can we get from mining asteroids?

If I asked you how many metals you think you have in your pockets at the moment, you might say three or four. But actually, you've probably got around 40 or 50 different metals on you right now if you've got a smartwatch on or a smartphone or even a tablet.

The problem with all those exotic metals is that they are quite rare and hard to get at on Earth. There's a limited supply and they're hard to recycle from the electronics we use. Therefore there is a huge demand and potentially a lot of money to be made by going to the asteroids and mining those as well as mining these resources on Earth.

Lewis Dartnell is an astrobiologist and professor of science communication at the University of Westminster

Asteroid mining could be an extremely profitable business

STARGAZER

ESSENTIAL GUIDES AND ADVICE FOR AMATEUR ASTRONOMERS

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What's in the sky?

Red light friendly

In order to preserve your night vision, you should read our observing guide under red light

© Giuseppe Donatiello

21 SEP
The Piscids reach their peak of five meteors per hour

25 SEP
Comet C/2018 W2 (Africano) is forecast to reach a magnitude of 6.6 in Pegasus

2 OCT
The Andromeda Galaxy (M31) is well placed at magnitude 3.4 in Andromeda

5 OCT
The Moon and Saturn make a close approach, passing within 0°15' of each other in Sagittarius

© Luc Viatour

6 OCT
The Moon and Pluto make a close approach, passing within 0°08 of each other in Sagittarius

Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

21 SEP 🔭★★★

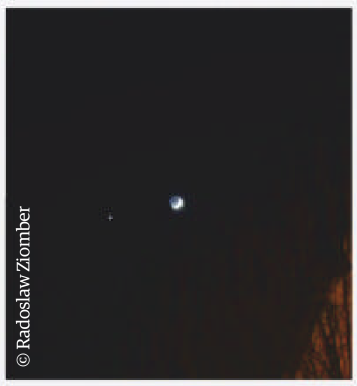
Comet 260P/McNaught is forecast to reach its brightest at a magnitude of 11.3 in Triangulum

23 SEP

September equinox

24 SEP 👓

The Moon and the Beehive Cluster (M44) pass within 0°42′ of each other in Cancer



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28 SEP 🔭★★★

Asteroid 21 Lutetia is well placed at magnitude 9.4 in Pisces

1 OCT 🔭★★

Messier 110 is well placed for observation at magnitude 8.1 in Andromeda

3 OCT 👁

Conjunction between the Moon and Jupiter in Ophiuchus

3 OCT 👁

The Moon and Jupiter make a close approach, passing within 1°50′ of each other in Ophiuchus

5 OCT 👁

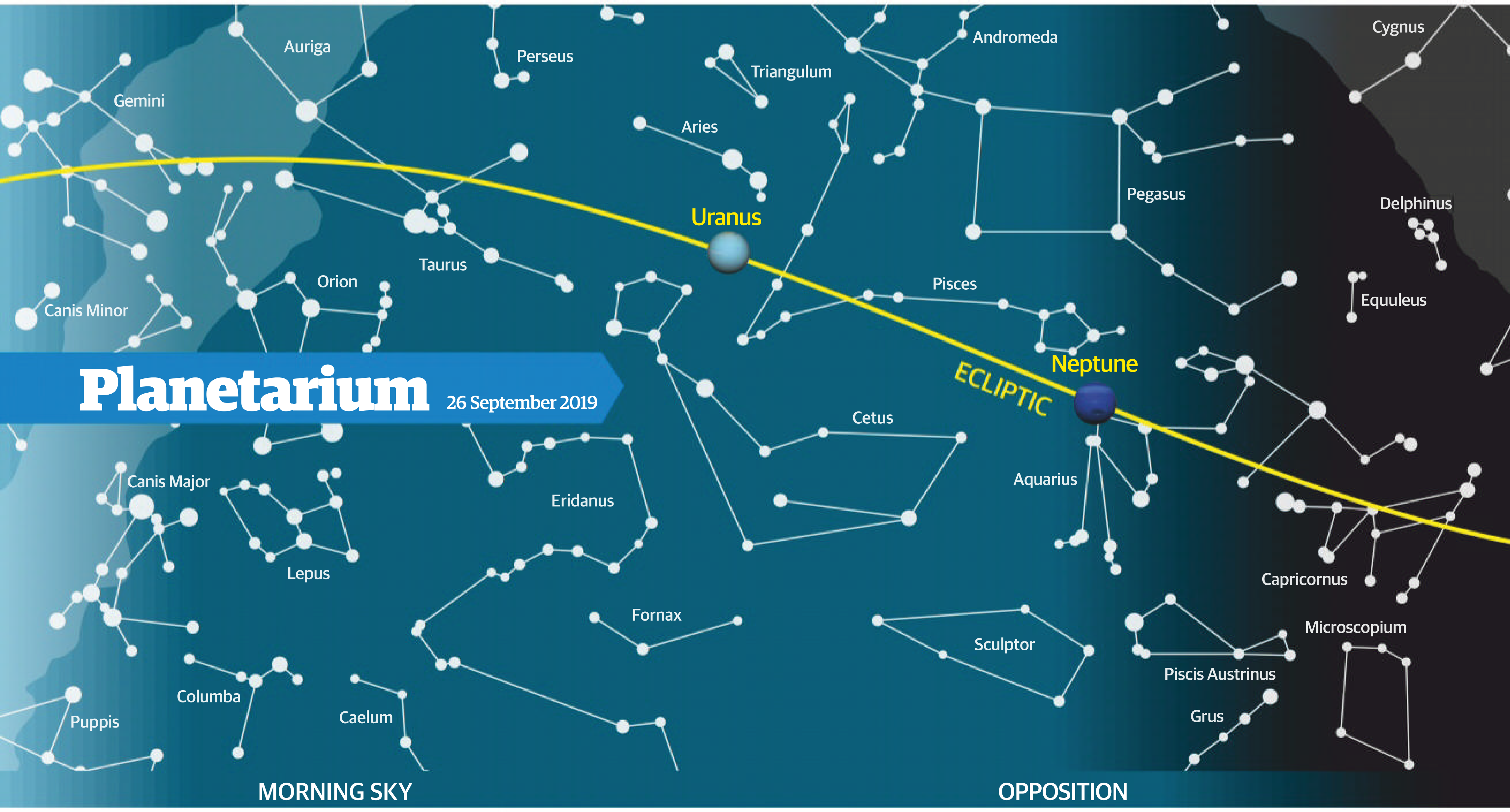
Conjunction of the Moon and Saturn in Sagittarius

👁 Naked eye
👓 Binoculars
🔭★ Small telescope
🔭★★ Medium telescope
🔭★★★ Large telescope

© Nasa/JPL

Planetarium

26 September 2019



Moon calendar

* The Moon does not pass the meridian on 12 October

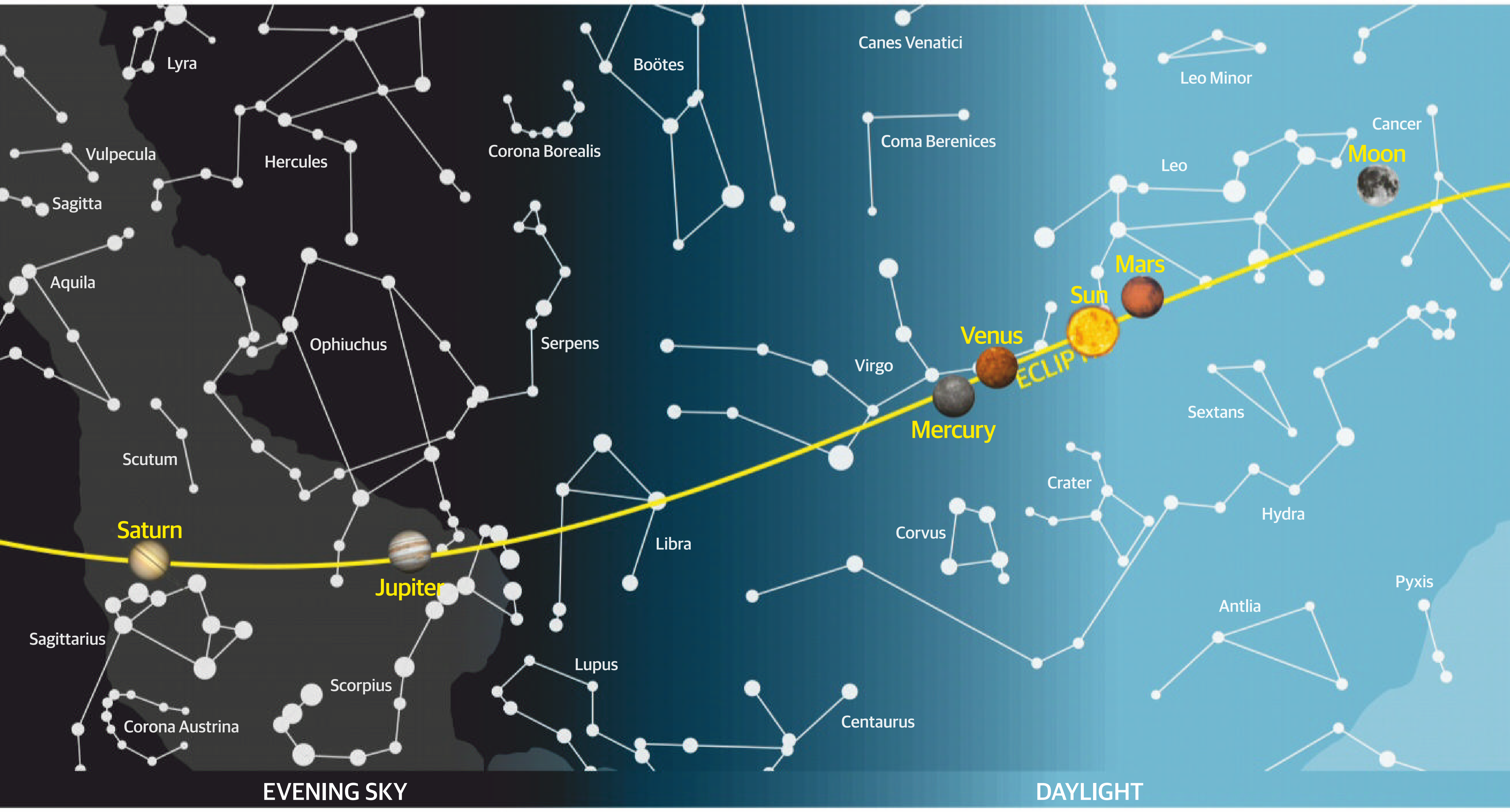
13 SEP		98.6%	▼05:19	▲19:35
14 SEP	FM	99.8%	▼06:25	▲19:54
15 SEP		99.2%	▼07:31	▲20:11
16 SEP		96.7%	▼08:37	▲20:29
17 SEP		92.4%	▼09:44	▲20:47
18 SEP		86.3%	▼10:52	▲21:08
19 SEP		78.7%	▼12:01	▲21:32
20 SEP		69.7%	▼13:01	▲22:03
21 SEP		59.6%	▼14:19	▲22:42
22 SEP	LQ	48.6%	▼15:23	▼23:31
23 SEP		37.4%	▼16:20	▲--:--
24 SEP		26.5%	▲00:34	▼17:08
25 SEP		16.5%	▲01:47	▼17:47
26 SEP		8.4%	▲03:09	▼18:19
27 SEP		2.8%	▲04:35	▼18:45
28 SEP	NM	0.3%	▲06:02	▼19:09
29 SEP		1.1%	▲07:28	▼19:32
30 SEP		5.0%	▲08:54	▼19:56
1 OCT		11.5%	▲10:17	▼20:21
2 OCT		20.0%	▲11:37	▼19:40
3 OCT		29.8%	▲12:53	▼21:26
4 OCT		40.2%	▲14:01	▼22:09
5 OCT	FQ	50.6%	▲14:59	▼22:59
6 OCT		60.8%	▲15:47	▼23:57
7 OCT		70.2%	▼--.--	▲16:25
8 OCT		78.8%	▼00:59	▲16:56
9 OCT		86.1%	▼02:04	▲17:21
10 OCT		92.0%	▼03:09	▲17:42
11 OCT		96.4%	▼04:16	▲18:01

% Illumination
▲ Moonrise time
▼ Moonset time

FM Full Moon
NM New Moon
FQ First quarter
LQ Last quarter

All figures are given for 00h at midnight (local times for London, UK)

What's in the sky?



Illumination percentage

	19 SEP	26 SEP	03 OCT	10 OCT
MERCURY	90%	90%	90%	80%
VENUS	100%	100%	100%	100%
MARS	100%	100%	100%	100%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

Planet positions

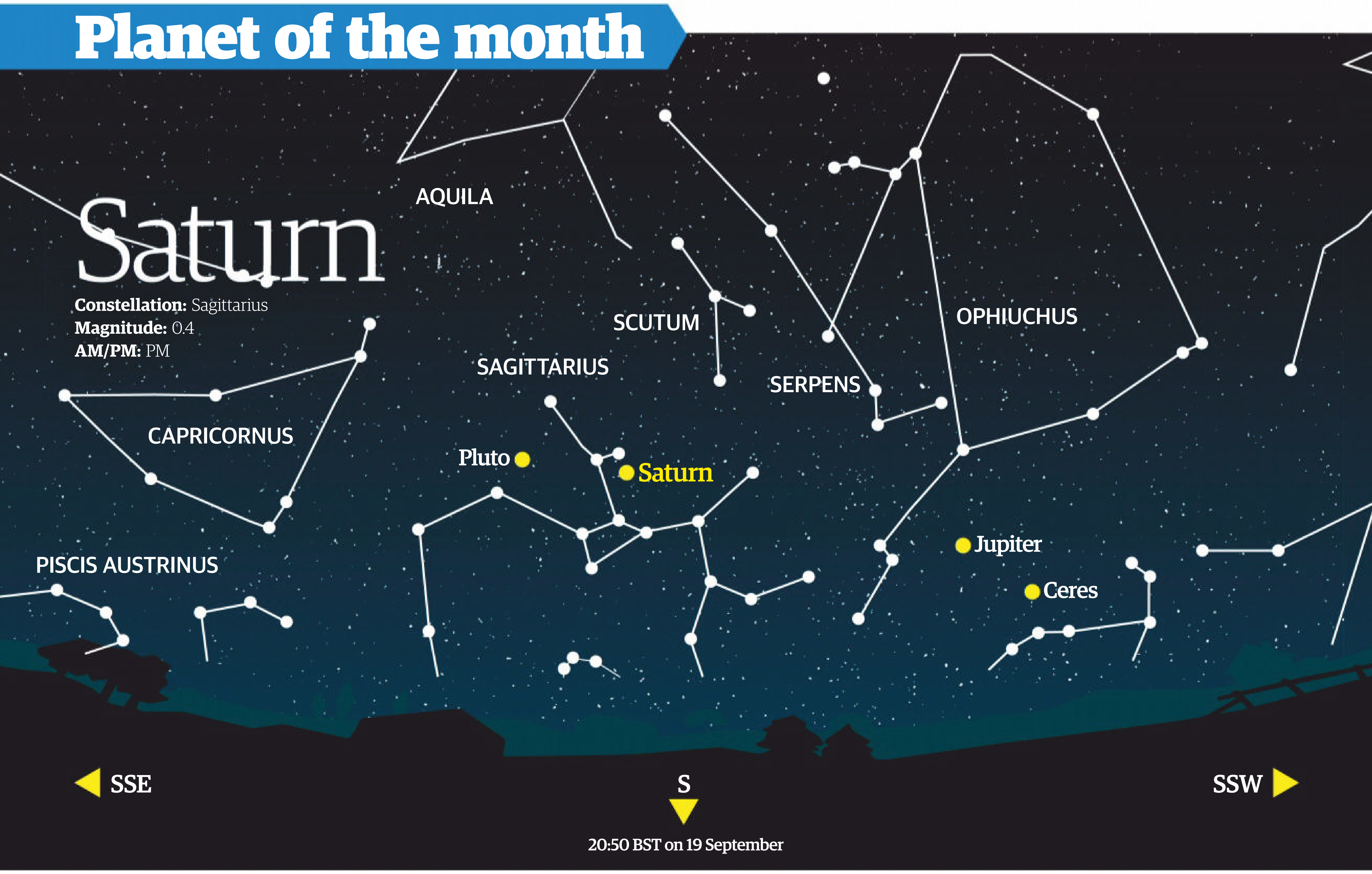
All rise and set times are given in BST

	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	13 Sep	11h 52m 26s	+02° 00' 25"	Virgo	-1.0	07:20	19:47
	19 Sep	12h 29m 00s	-02° 38' 02"	Virgo	-0.6	07:56	19:37
	26 Sep	13h 09m 01s	-07° 44' 16"	Virgo	-0.3	08:34	19:23
	03 Oct	13h 46m 58s	-12° 21' 47"	Virgo	-0.2	09:09	19:09
	10 Oct	14h 23m 01s	-16° 22' 17"	Libra	-0.1	09:40	18:55
VENUS	13 Sep	11h 53m 59s	+02° 05' 47"	Virgo	-3.9	07:21	19:49
	19 Sep	12h 21m 10s	-00° 57' 26"	Virgo	-3.9	07:40	19:37
	26 Sep	12h 52m 57s	-04° 31' 08"	Virgo	-3.9	08:02	19:24
	03 Oct	13h 25m 02s	-08° 00' 45"	Virgo	-3.9	08:24	19:10
	10 Oct	13h 57m 38s	-11° 21' 55"	Virgo	-3.9	08:47	18:58
MARS	13 Sep	11h 10m 40s	+06° 25' 38"	Leo	1.8	19:28	20:50
	19 Sep	11h 24m 50s	+04° 54' 30"	Leo	1.8	19:11	20:30
	26 Sep	11h 41m 19s	+03° 06' 44"	Virgo	1.8	18:51	20:11
	03 Oct	11h 57m 47s	+01° 17' 57"	Virgo	1.8	18:30	19:51
	10 Oct	12h 14m 17s	-00° 31' 17"	Virgo	1.8	18:10	19:31
JUPITER	13 Sep	16h 58m 31s	-22° 22' 29"	Ophiuchus	-2.2	14:39	22:39
	19 Sep	17h 01m 09s	-22° 27' 14"	Ophiuchus	-2.1	14:18	22:17
	26 Sep	17h 04m 42s	-22° 33' 11"	Ophiuchus	-2.1	13:55	21:53
	03 Oct	17h 08m 46s	-22° 39' 22"	Ophiuchus	-2.1	13:32	21:29
	10 Oct	17h 13m 16s	-22° 45' 38"	Ophiuchus	-2.0	13:10	21:05
SATURN	13 Sep	18h 59m 15s	-22° 31' 36"	Ophiuchus	0.4	16:40	00:42
	19 Sep	18h 59m 10s	-22° 32' 21"	Ophiuchus	0.4	16:16	00:18
	26 Sep	18h 59m 22s	-22° 32' 45"	Ophiuchus	0.4	15:49	23:47
	03 Oct	18h 59m 56s	-22° 32' 39"	Ophiuchus	0.5	15:22	23:20
	10 Oct	19h 00m 50s	-22° 32' 01"	Ophiuchus	0.5	14:55	22:54

This month's planets

Saturn rules the evening skies, offering astronomers the chance to track its largest moon Titan and its stunning ring system

Planet of the month



Saturn

Constellation: Sagittarius
Magnitude: 0.4
AM/PM: PM

20:50 BST on 19 September

Unlike its Sun-hugging siblings Mercury, Venus and Mars, all through our observing period Saturn will be an easy naked-eye object. The best way to pin it down is probably to find Jupiter first, then use that planet as a guide to find Saturn: as the sky darkens after sunset brilliant Jupiter will quickly pop into view above the southern horizon, and if you look a short distance over to its left you'll find a yellow-white 'sta}r, much fainter than Jupiter, shining to the upper left of the handle of the famous 'Teapot' asterism of the lovely constellation of Sagittarius.

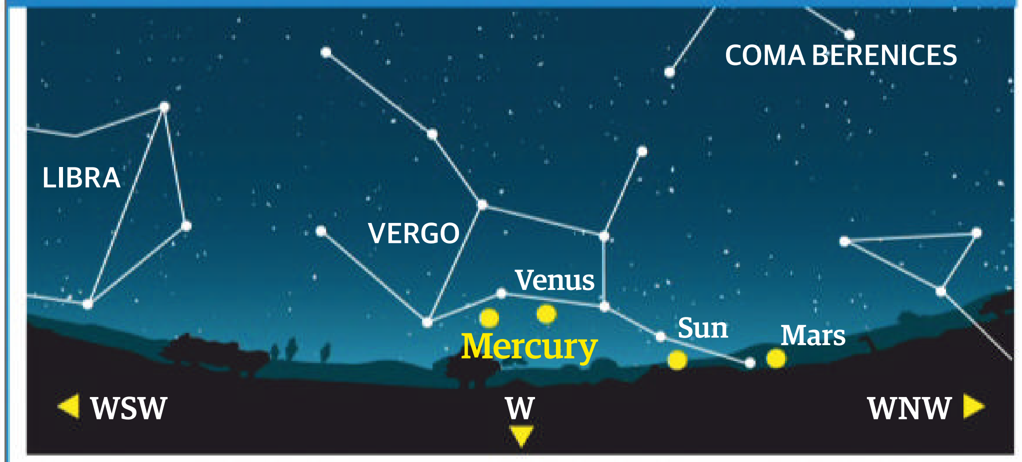
Unfortunately this constellation never climbs very high in the sky as seen from mid-northern latitudes, so the famous ringed planet can't do at the moment either, and is spending the whole of the summer and autumn low in the south, skirting the tops of trees, buildings and low hills, so to see Saturn you might need to get to an observing site that's both high up and has a clear view to the south.

Having found Saturn with your naked eye, you'll obviously want to see its rings, but they can't be seen without a telescope, and even the highest powered binoculars will only hint at their presence. What a pair of binoculars of any size will show you, though, is Saturn's largest moon, Titan. This moon is the size of the planet Mercury, and in binoculars it looks like a tiny 'star' shining very close to the planet itself.

Titan is in the news at the moment because in June 2019 NASA announced it was sending an exciting new mission to the moon. Scientists have wanted to send another space probe to Titan ever since the European Space Agency's Huygens lander touched down on it in 2005. When it launches in 2026, the much more ambitious 'Dragonfly' mission will send a large, nuclear-powered, four-rotor drone-type vehicle to Titan. After arriving in the Saturn system in 2034 Dragonfly will land on Titan's frozen surface and then begin to fly around its fascinating landscape, hop-scotching between different features of interest. Planetary scientists and space enthusiasts alike are hoping that after landing safely the Dragonfly's cameras will send back breathtaking images of Titan's methane lakes, ice mountains and plains of dark, windblown dunes. Other instruments will analyse the moon's smoggy atmosphere and surface material, and very excitingly will also test for evidence of life on its icy surface.

This month Saturn has a close encounter with our Moon. If you look for the planet as darkness falls on the evening of 5 October, you'll see the first quarter Moon shining close to it.

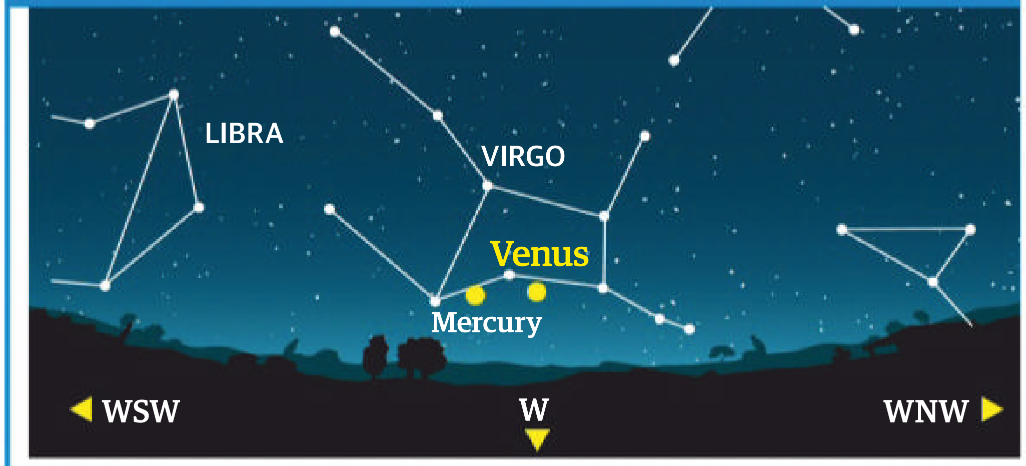
Mercury 18:50 BST on 25 September



Constellation: Virgo
Magnitude: -1.0
AM/PM: PM

This is another really bad month if you enjoy tracking down the closest planet to the Sun. At the start of our observing period Mercury - named after the messenger of the gods - can be found close to brighter Venus in the west after sunset, but the pair will be so close to the Sun in the sky that they won't be readily visible.

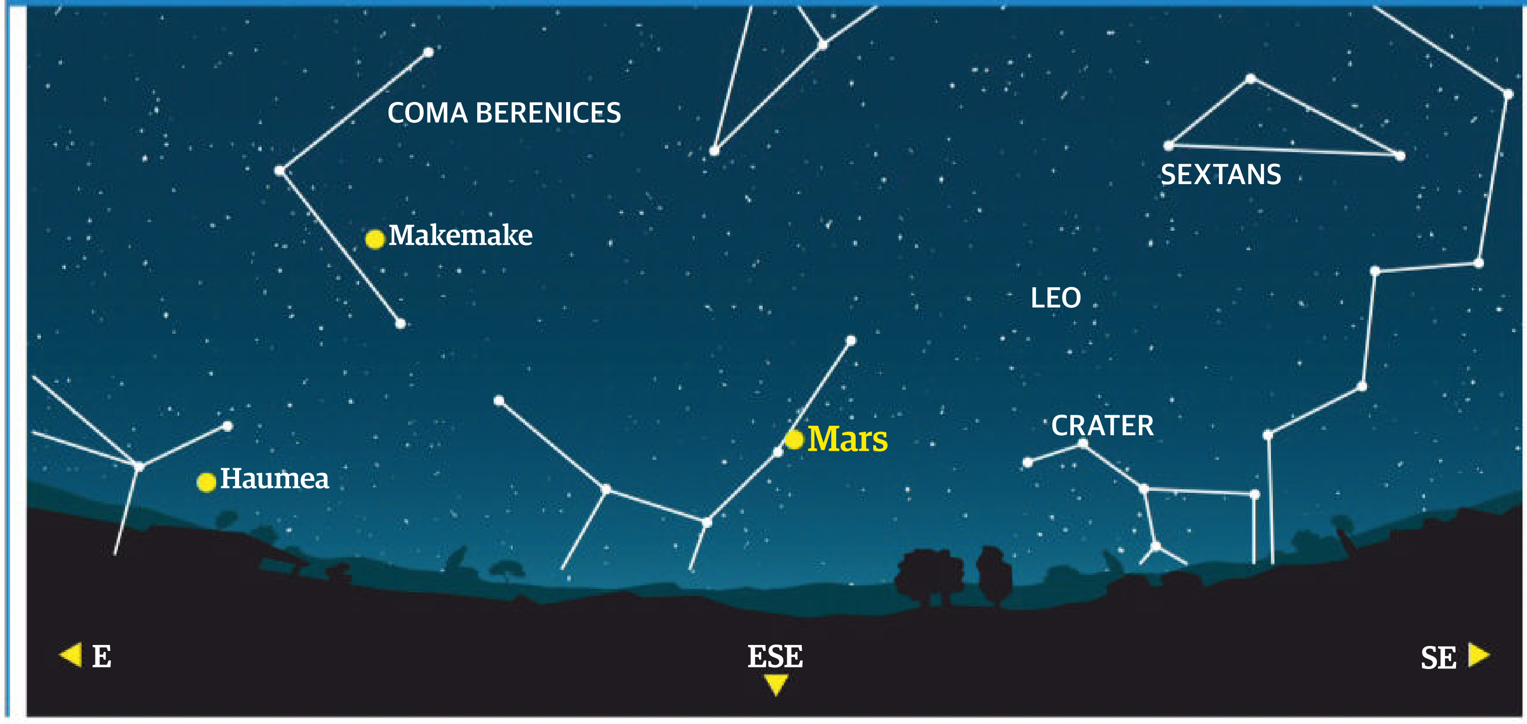
Venus 19:00 BST on 26 September



Constellation: Virgo
Magnitude: -3.9
AM/PM: PM

Looking at that magnitude of -3.9 you would be forgiven for thinking that Venus will be a very easy naked-eye planet this month, but sadly that's misleading. Venus will be so close to the Sun that its bright light will be greatly diminished visually, and it will be so low in the sky that any trees or buildings will cover it up.

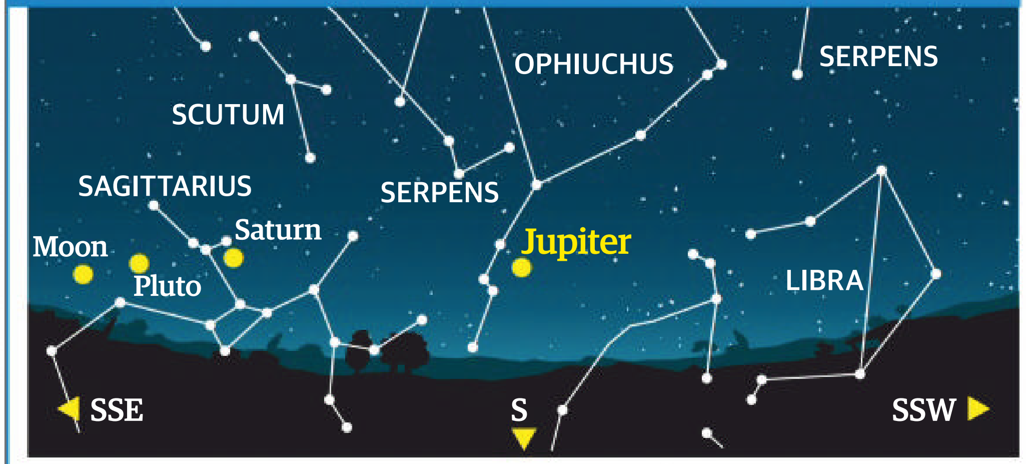
Mars 07:00 BST on 10 October



Constellation: Leo
Magnitude: 1.7
AM/PM: AM

Unfortunately this is another bad month for you if you're a fan of the famous Red Planet. At the start of our observing period Mars is so close to the Sun that it won't be visible, but as the days pass the only planet in the Solar System inhabited entirely by robots will begin to pull away from the Sun, and its visibility will improve a little as it begins to drag itself up into the predawn eastern sky. By the middle of October Mars will be rising an hour before the Sun in a reasonably dark sky, but at magnitude 1.7 it will still look like just another star, not striking in any way... it's much better next month!

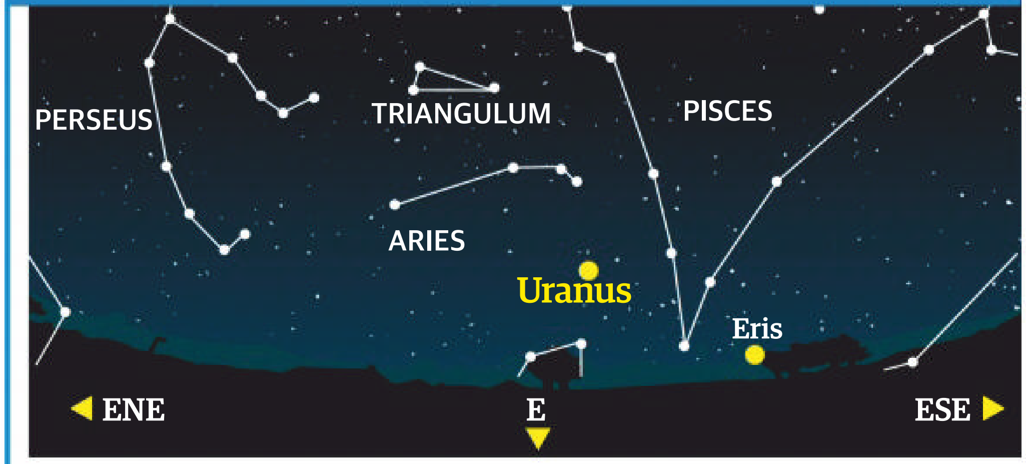
Jupiter 18:00 BST on 6 October



Constellation: Ophiuchus
Magnitude: -2.1
AM/PM: PM

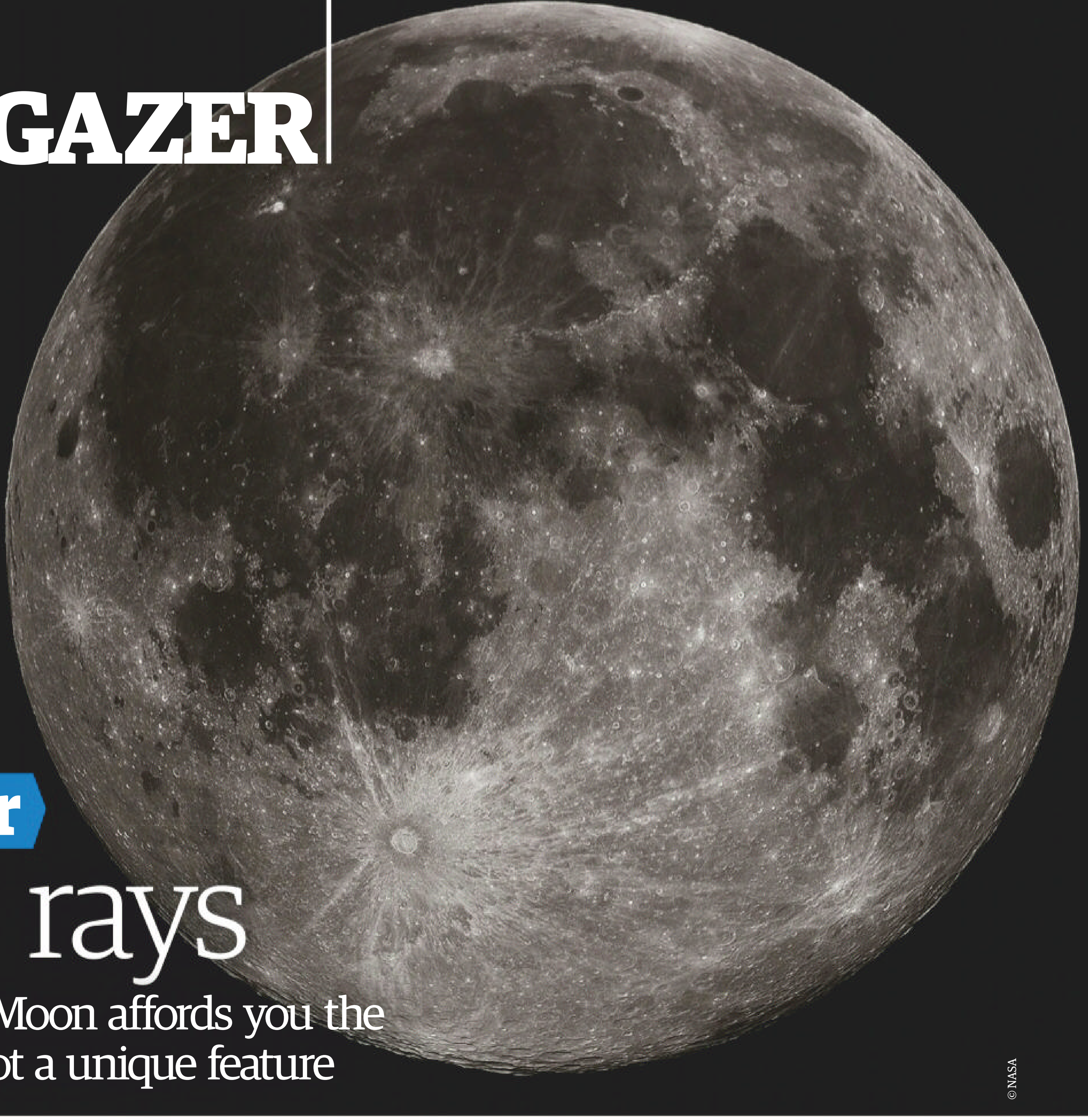
During our observing period Jupiter, largest of all the planets, is a strikingly bright naked-eye 'star'. It never climbs high in the sky, remaining to the upper left of ruddy Antares, brightest star in Scorpio, but it becomes visible straight after sunset as a silvery spark in the south, and doesn't set until late in the evening.

Uranus 20:00 BST on 9 October



Constellation: Aries
Magnitude: 5.7
AM/PM: PM

Uranus is the most distant planet in our Solar System visible to the naked eye - but only just. At magnitude 5.7 it is technically just bright enough to be seen without assistance. At the start of our observing period Uranus will rise in the ENE around 22:30, then slowly cross the horizon, fading from view as the sky brightens at sunrise.



© NASA

Top tip!

A pair of binoculars or a small telescope will give you a fantastic view of the Moon's rays.

Moon tour

Lunar rays

This month's full Moon affords you the opportunity to spot a unique feature

Astronomers are often asked when the best time to look at the Moon is. The obvious answer would seem to be when it's full, because the full Moon is the biggest and brightest phase. But if you're wanting to see details on the Moon then full Moon is absolutely the worst time. To see the Sun-drenched peaks of its towering mountains, the frigid depths of its deepest craters and the floors of the valleys which weave and wander across its surface, you need to be looking into your telescope's eyepiece when the Moon is a crescent, or quarter phase - with the Sun's rays hitting those geological landmarks at an angle it will cast stark shadows behind them, and they will stand out in amazing clarity.

However, the full Moon isn't as useless as some astronomers would have you believe. Then, when the Sun is shining right down on it, is absolutely the best time to see the famous 'Man in the Moon' - the pareidoliac face formed in our minds by the dark mare, or seas, on the Moon's Earth-facing side. It is also the best time to see the Moon's 'rays' - long, bright lines that appear to have been painted on its surface by some crazed artist.

The lunar rays are actually long trails of rocky and dusty debris that were sprayed across the Moon by the cataclysmic impacts which formed some of its largest and youngest craters. And when the Moon is full even your naked eye is powerful enough to show you the rays that surround and stretch away from four of the nearside's most famous and attractive craters.

How do they form? Imagine you're standing on the Moon one day 108 million years ago, somewhere near the equator, in the middle of the side of the Moon facing Earth. Suddenly, without warning, an asteroid between eight kilometres (five miles) and ten kilometres (6.2 miles) wide slams into the Moon to the south of you. After the blinding flash you see a huge plume of dust rising up into the sky, and fires raging beneath it. After a short time you would find yourself under a hail of rocks, big and small - debris from the impact. Cowering and looking up at the sky, you would see a long streamer of debris arcing across it, falling down to the surface to leave behind a long, light-coloured line of pulverised rock and dust: a lunar ray.

This month's full Moon - which falls on 14 September - offers great views of the ray systems surrounding four of the most famous lunar craters. All can be seen with the naked eye, not just when the Moon is full but when it is new too, when no or very little sunlight is bathing it and it is lit by a ghostly light reflecting off the Earth, known as Earthshine. Total lunar eclipses also offer great opportunities for a Moon observer to view some rays, bathed in a beautiful ruddy glow.

The largest system of rays surrounds the great crater Tycho. Tycho lies down near the bottom of the Moon's disc and was formed around 800 million years ago. Looking up at the Moon on that fateful day, the prehistoric life roaming Earth at the time would have seen a bright flash as a chunk of space rock ten kilometres (6.2 miles) wide slammed into the Moon, blasting out a crater 85 kilometres (53 miles) wide and almost five kilometres (three miles) deep. Huge amounts of debris splashed out by the impact fell in long lines across the lunar landscape, leaving bright rays up to 1,500 kilometres (932 miles) in length. Those ancient creatures are long gone, but today we can see Tycho's rays radiating away from it for incredible distances.

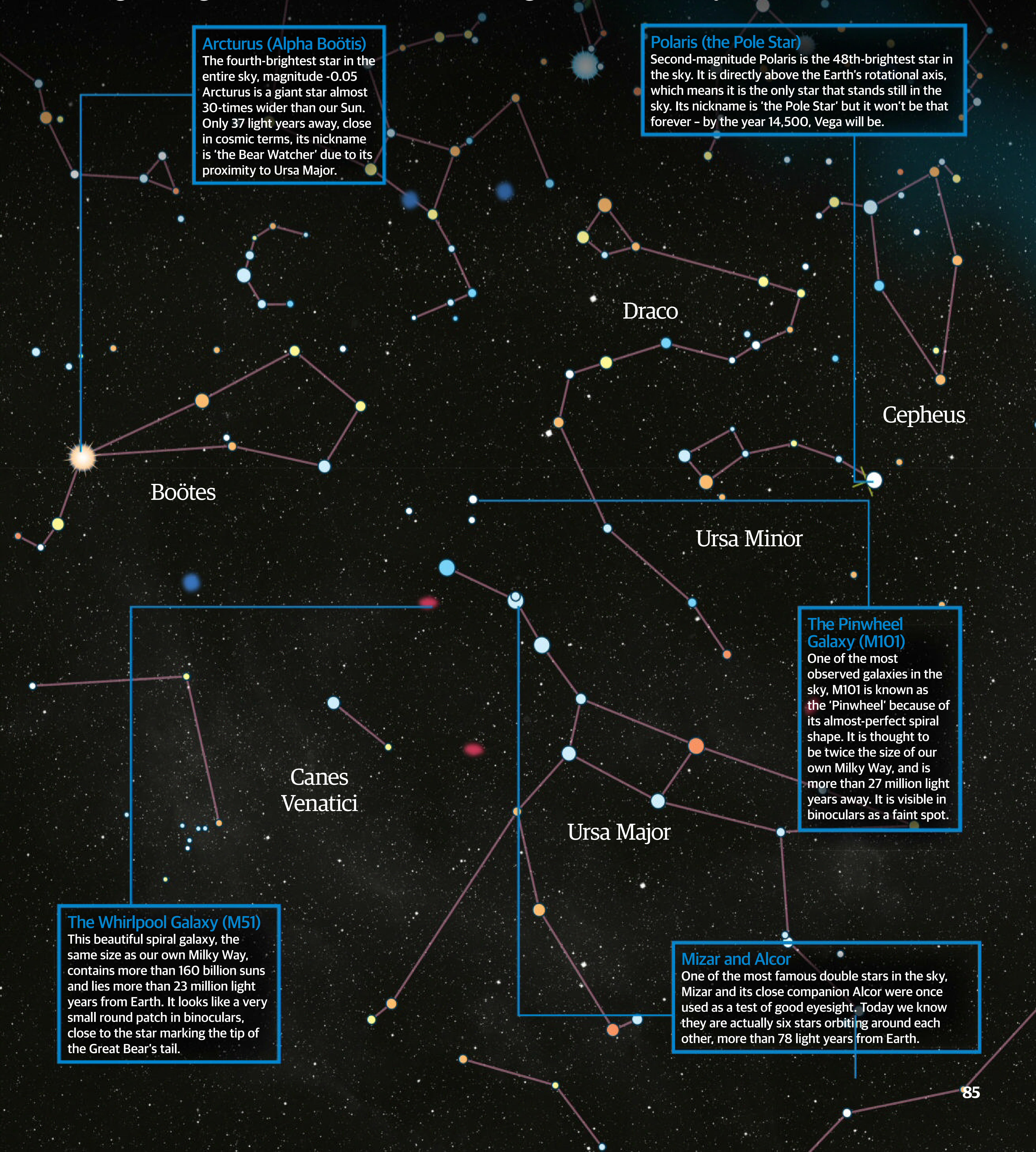
To the upper left of Tycho, to the top left of the Moon's face, lies a trio of bright, young craters with ray systems that are all obvious to the naked eye. The largest of the three, Copernicus, is nicknamed 'the Monarch of the Moon' because of its impressive size, and this 96 kilometre (60 miles) wide and four kilometre (2.5 miles) deep crater is surrounded by a very obvious system of rays, the longest of which stretch for 800 kilometres (497 miles).

To Copernicus' left lies the smaller crater, Kepler. Despite being only 29 kilometres (18 miles) across, Kepler is easily seen by the naked eye as a bright spot in the centre of a very striking spray of bright rays.

Above and to the left of Kepler, close to the Moon's limb, is Aristarchus. With a diameter of 40 kilometres (25 miles) it is actually larger than Kepler, but it appears smaller due to its proximity to the limb. Aristarchus has a small spray of bright rays to its southeast.

Naked eye & binocular targets

Find glittering stars and 'Catherine Wheel' galaxies in the sky



Arcturus (Alpha Boötis)

The fourth-brightest star in the entire sky, magnitude -0.05 Arcturus is a giant star almost 30-times wider than our Sun. Only 37 light years away, close in cosmic terms, its nickname is 'the Bear Watcher' due to its proximity to Ursa Major.

Polaris (the Pole Star)

Second-magnitude Polaris is the 48th-brightest star in the sky. It is directly above the Earth's rotational axis, which means it is the only star that stands still in the sky. Its nickname is 'the Pole Star' but it won't be that forever – by the year 14,500, Vega will be.

The Pinwheel Galaxy (M101)

One of the most observed galaxies in the sky, M101 is known as the 'Pinwheel' because of its almost-perfect spiral shape. It is thought to be twice the size of our own Milky Way, and is more than 27 million light years away. It is visible in binoculars as a faint spot.

The Whirlpool Galaxy (M51)

This beautiful spiral galaxy, the same size as our own Milky Way, contains more than 160 billion suns and lies more than 23 million light years from Earth. It looks like a very small round patch in binoculars, close to the star marking the tip of the Great Bear's tail.

Mizar and Alcor

One of the most famous double stars in the sky, Mizar and its close companion Alcor were once used as a test of good eyesight. Today we know they are actually six stars orbiting around each other, more than 78 light years from Earth.

Deep sky challenge

Discover Ursa Major

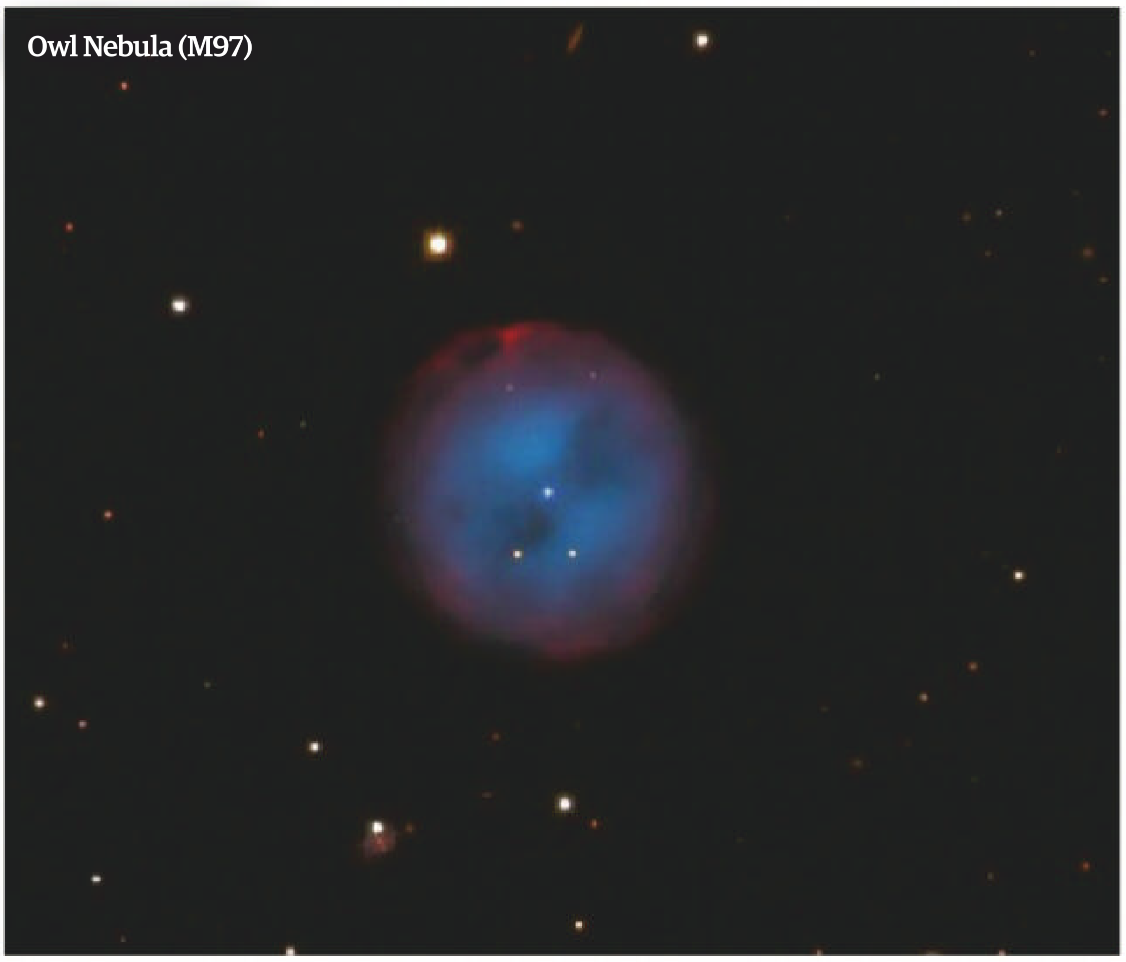
Explore obscure deep-sky wonders lurking far, far beyond the stars of the Great Bear

Although almost unimaginably far away compared to our own Sun, in cosmic terms the familiar stars of the Big Dipper are quite close to the Earth - all between 80 and 123 light years away. But when you look at and through the Big Dipper you're looking away from the Milky Way's cluttered star clouds, past its frothy, curving spiral arms and out into the endless depths of space. This month your deep-sky targets all lie many thousands or even many millions of light years away, and are all so faint you will definitely need a large telescope to bag them all. Most are remote, exotic galaxies, far beyond the outer rim of our own Milky Way, but one is a famously odd-looking planetary nebula, the ghostly remains of a once-proud star that exploded more than 6,000 years ago. So, time to swing your telescope around to face the north, slot in your best eyepiece and start hunting.

> "Spy remote, exotic galaxies, far beyond the outer rim of our own Milky Way"

NGC 5005

© NASA/ESA



Owl Nebula (M97)

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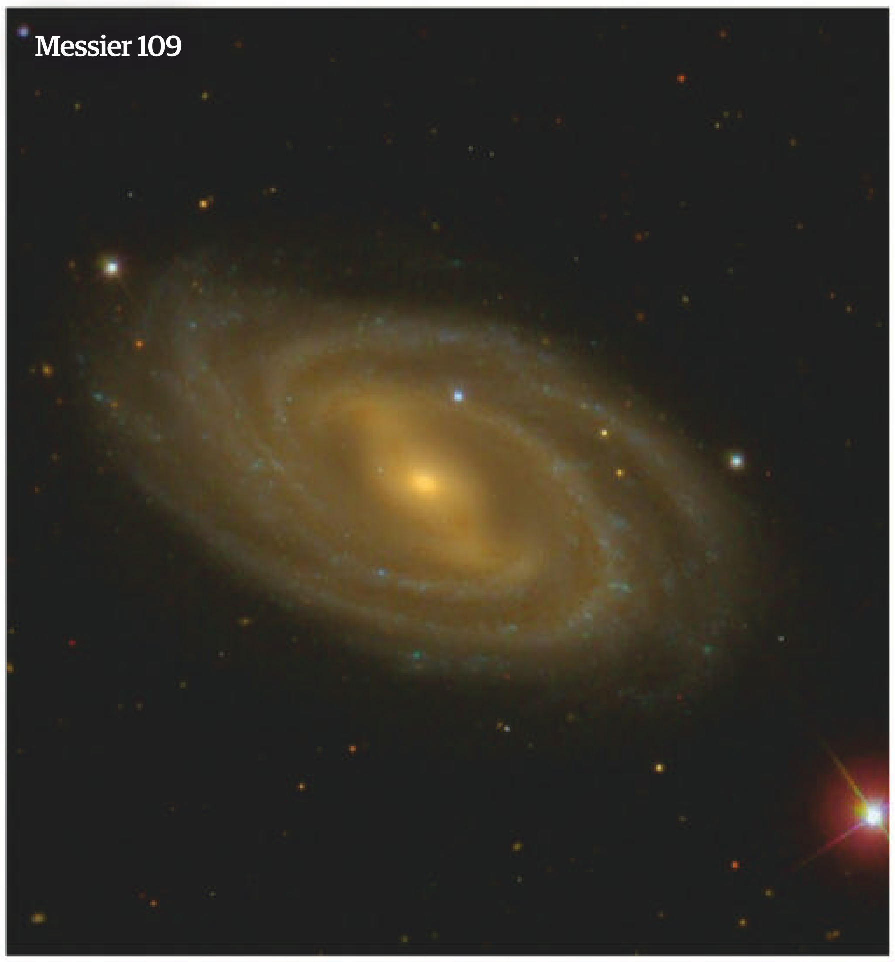

Messier 109

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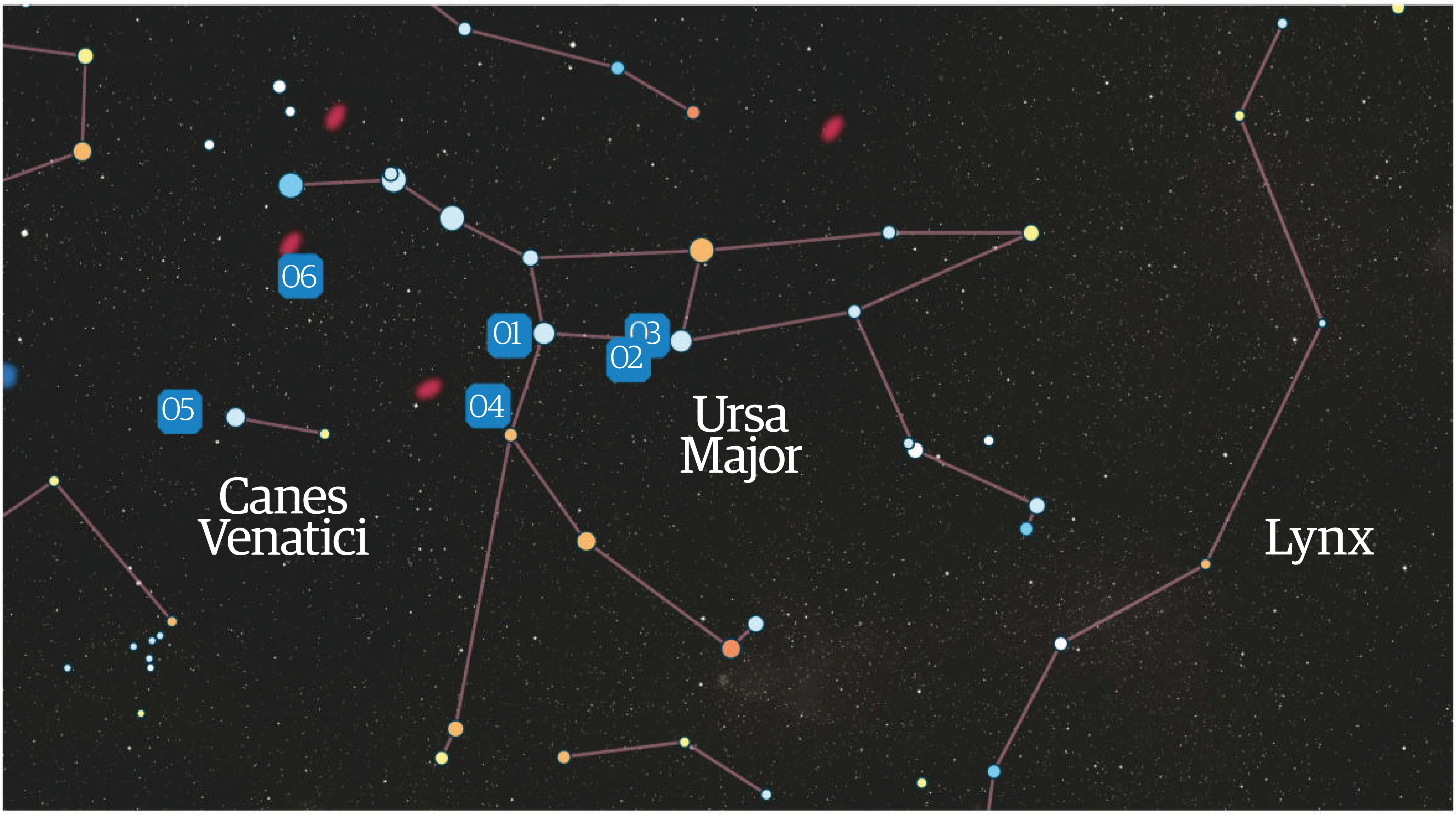

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1 Messier 109 (NGC 3992)

This barred-spiral galaxy lies 84 million light years away. At magnitude 9.6 it only looks like a small pear-shaped smudge in small telescopes. Larger instruments show its mottled centre.

2 The Owl Nebula (M97)

This popular magnitude 9.8 planetary nebula has a blue-green tinge and a pair of dark lobes within its puffy disc which give it the appearance of an owl's face.

3 Messier 108

This tenth-magnitude edge-on spiral galaxy is 32 million light years away. Large telescopes show it as a small, faint streak with a bright centre and mottling along its length.

4 NGC 3928

This elliptical galaxy is so faint that it can only be seen through large-aperture instruments. Even then it is just a very small, circular smudge in a high-power eyepiece.

5 NGC 5005

This tenth-magnitude spiral galaxy is inclined to us, so large telescopes show it as a small, oval-shaped patch of light. High powers bring out hints of its dark dust lanes and bright central area.

6 NGC 5173

This magnitude 12 elliptical galaxy is over 130 million light years away, so you'll need a large telescope to see it. Even then it will only look like a tiny round smudge just one arc minute across.

The Northern Hemisphere

Now well into autumn, the darkened skies bring some astronomical favourites

Cassiopeia (the Queen) and Cepheus (the King) lie in the dusty path of the Milky Way, offering not just a rich star field, but impressive deep-sky objects. The Owl Cluster (NGC 457) is particularly easy to pick out with decent binoculars, its 75 to 100 bright stars forming the shape of an owl with spread wings, while its bright double star Phi Cassiopeiae comprise the celestial bird's eyes. Double star Alpha Cassiopeiae is easy to split, resolving a bright, yellow primary and faint, blue secondary and providing delightful views.

Use the constellations of Pegasus, Aquarius and Pisces and you'll be able to locate Cetus (the Sea Monster) which contains the remarkable variable star Mira, as well as a wide selection of galaxies.

Using the sky chart

This chart is for use at 22:00 (BST) mid-month and is set for 52° latitude.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.

Magnitudes

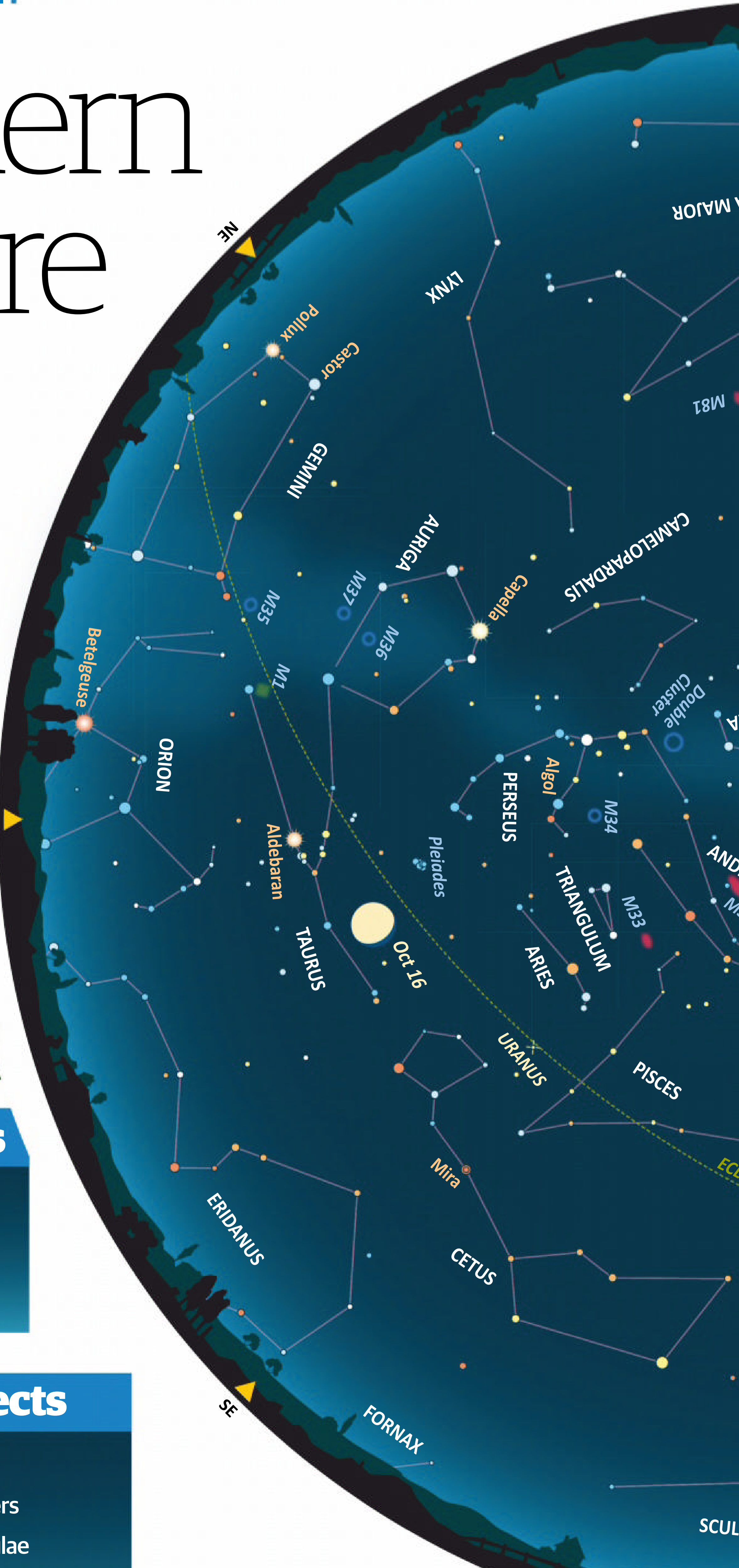
- ● Sirius (-1.4)
- ● -0.5 to 0.0
- ● 0.0 to 0.5
- ● 0.5 to 1.0
- ● 1.0 to 1.5
- • 1.5 to 2.0
- • 2.0 to 2.5
- • 2.5 to 3.0
- • 3.0 to 3.5
- · 3.5 to 4.0
- · 4.0 to 4.5
- · Fainter
- ◉ Variable star

Spectral types

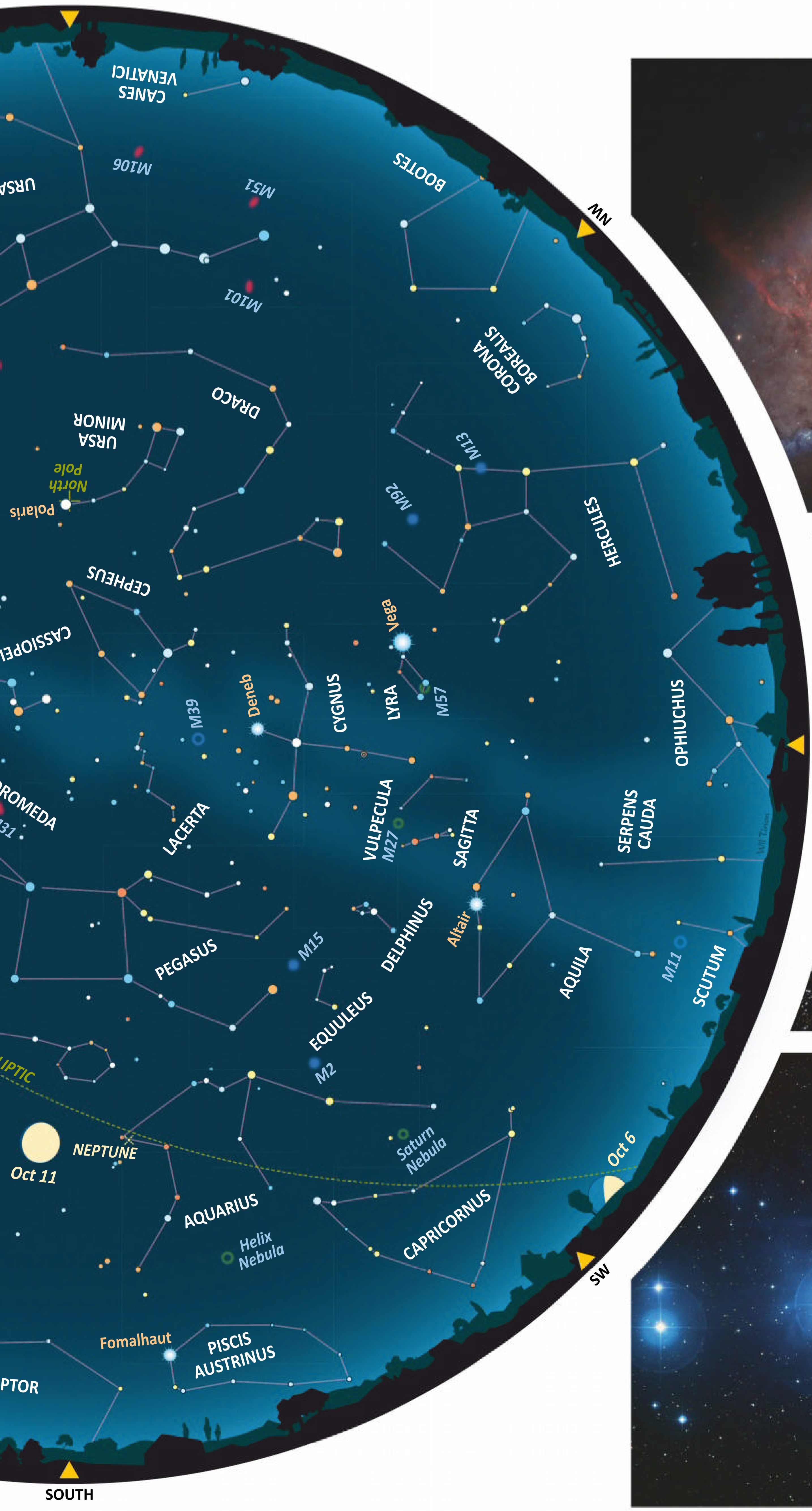
- ● O-B
- ● A
- ● F
- ● G
- ● K
- ● M

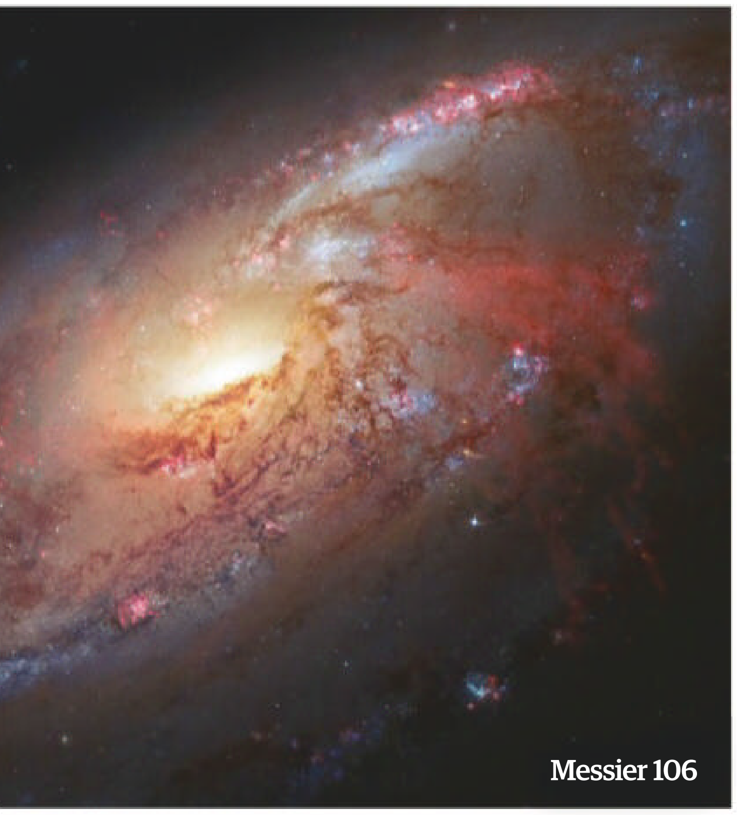
Deep-sky objects

- ○ Open star clusters
- ● Globular star clusters
- 🟩 Bright diffuse nebulae
- ○ Planetary nebulae
- ⬮ Galaxies

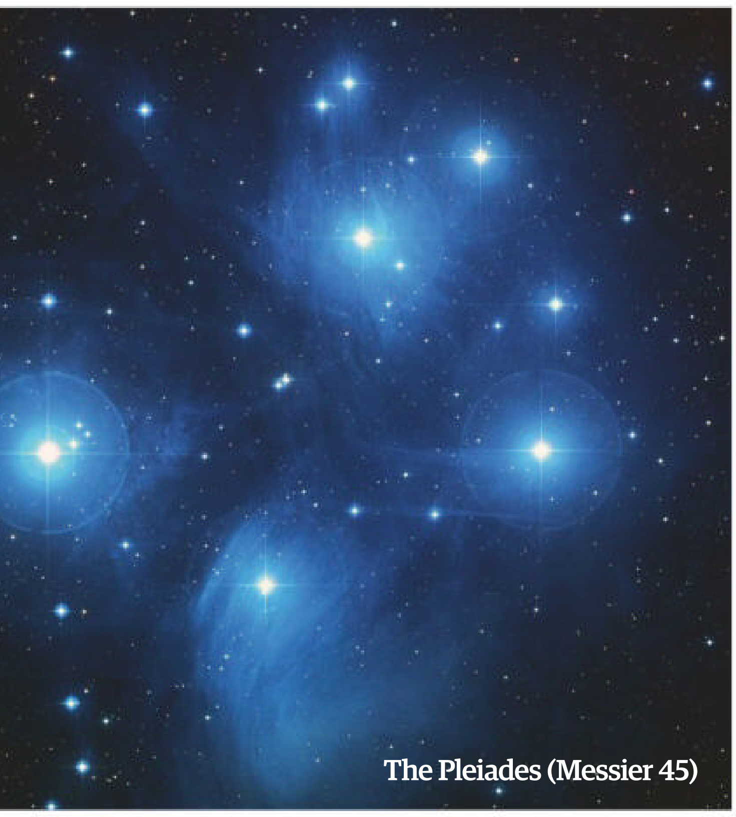


Observer's note:
The night sky as it appears on 17 October 2019 at approximately 22:00 (BST)




Messier 106

Messier 92


The Pleiades (Messier 45)

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STARGAZER

Astroshots of the month

Drakensberg, South Africa

Send your astrophotography images to **space@spaceanswers.com** for a chance to see them featured in **All About Space**

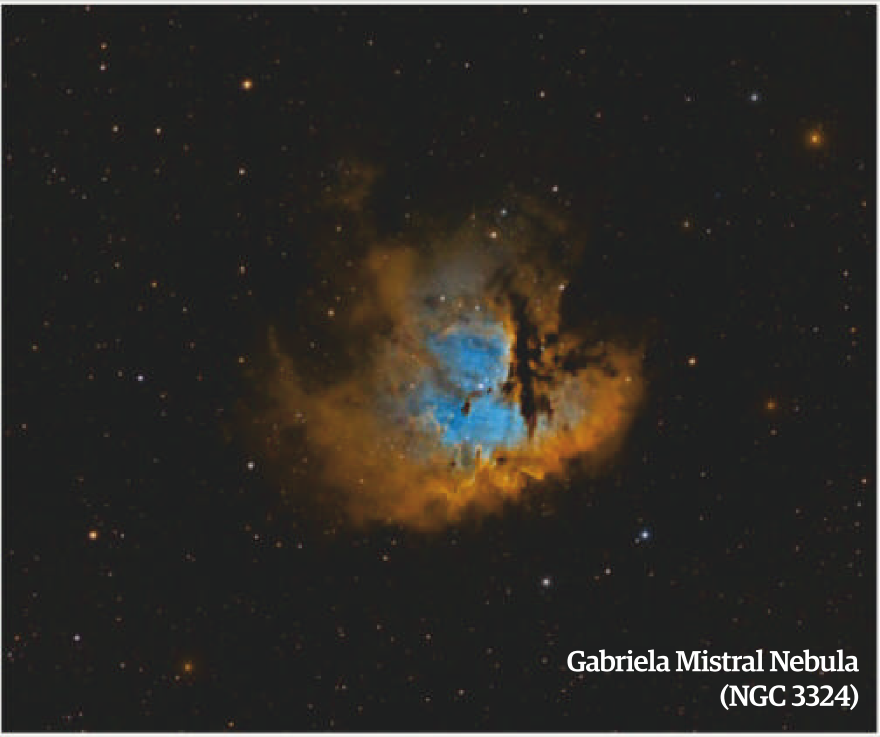
Tanja Schmitz

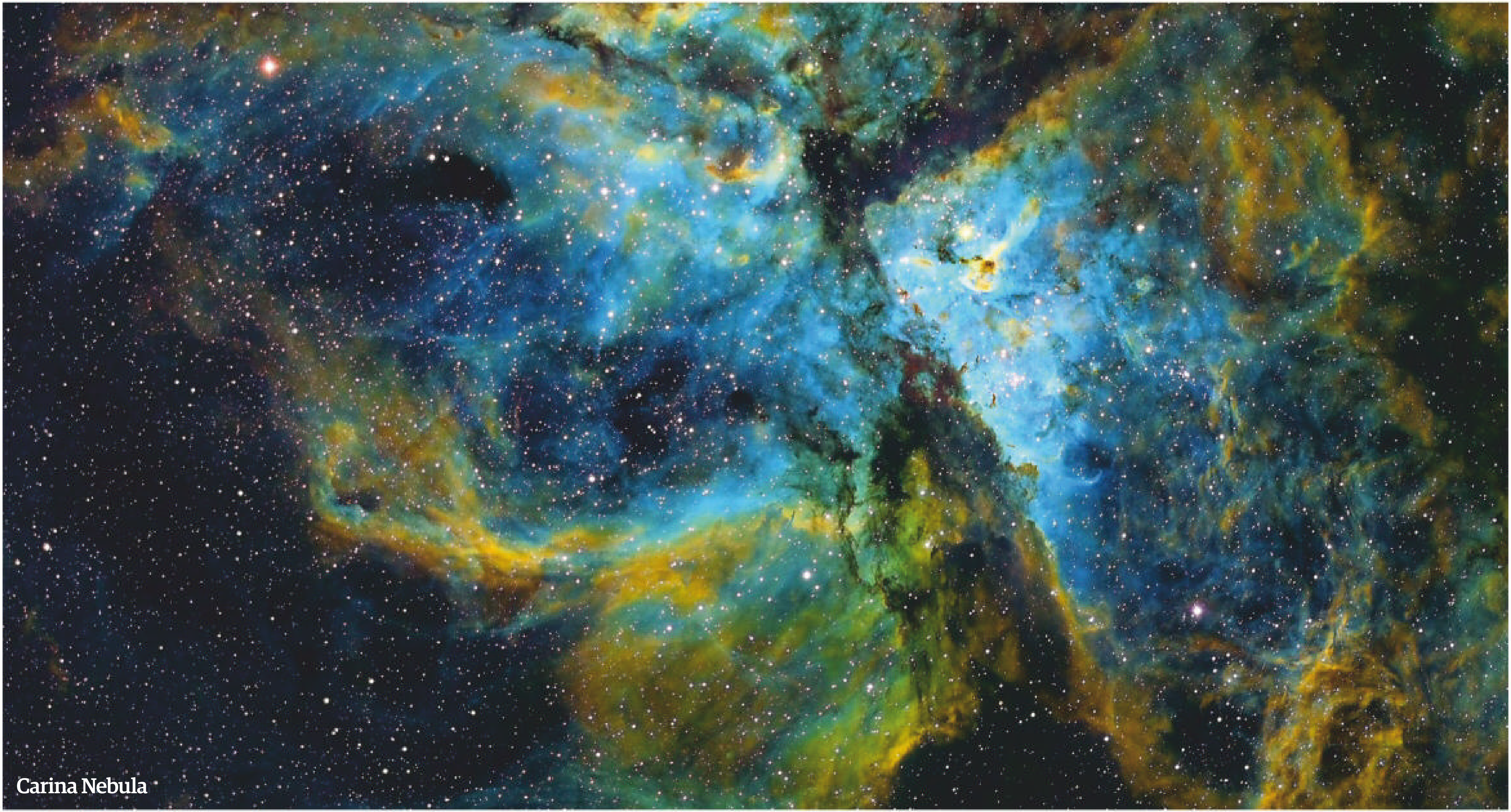
Johannesburg, South Africa

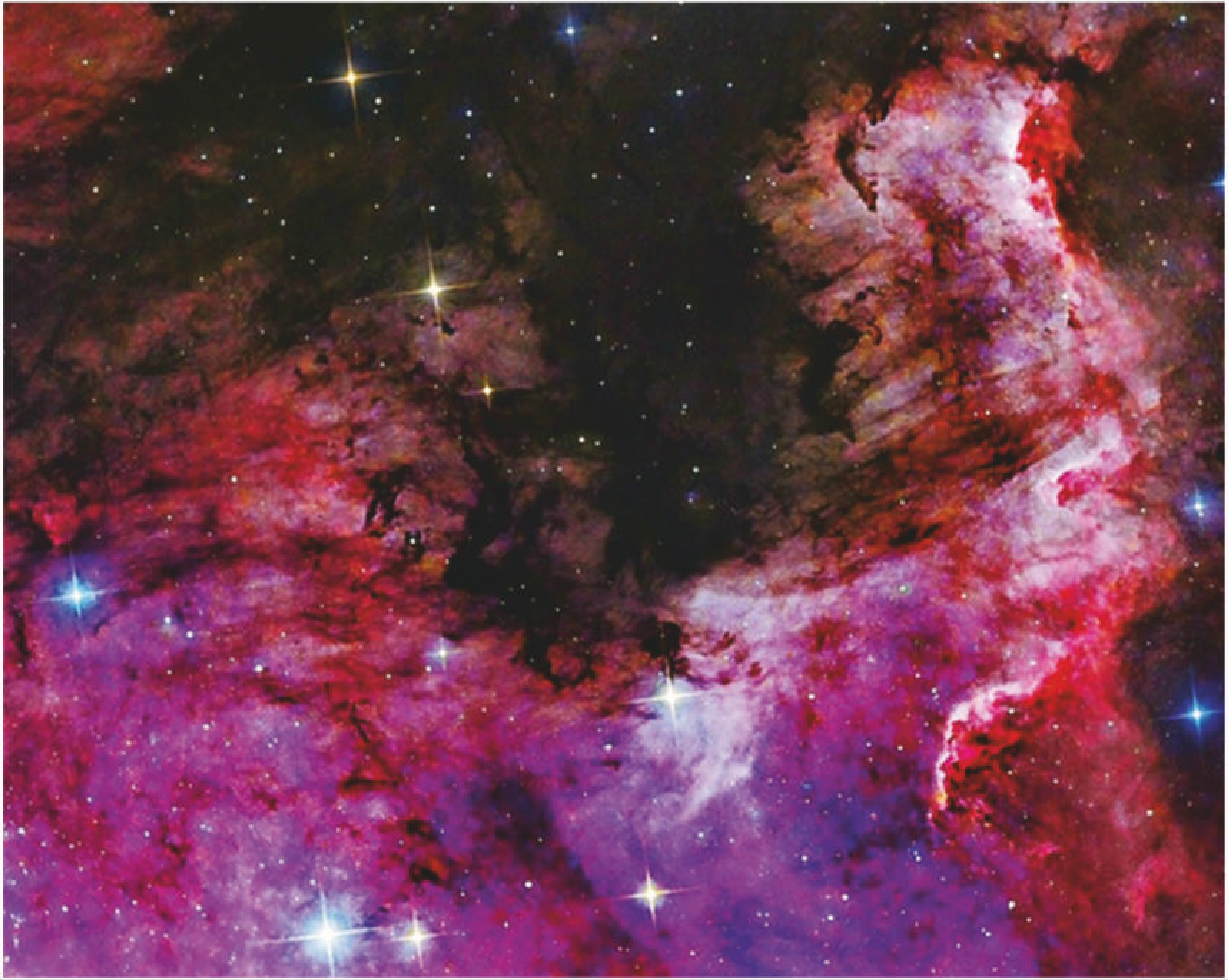
Telescope:
Officina Stellare Hiper APO 150 and Orion eight-inch Astrograph

"Being based in the Southern Hemisphere gives me access to some of the most exquisite targets and dark skies, although I often have to travel far to access them – my husband, who is also an astrophotographer, and I travel to locations untouched by light pollution. I've been photographing the night sky for three years, and although it's a tough balancing act between daytime life and pursuing the hobby at night, it's well worth the time I spend capturing the night sky.

"I've realised that it's not necessarily the quality of the equipment that you use, but rather your determination and commitment that results in great images."


Gabriela Mistral Nebula (NGC 3324)


Carina Nebula



Terry Hancock

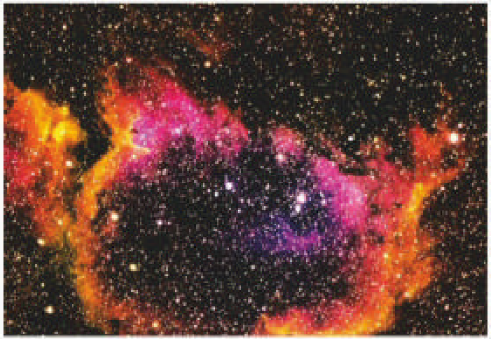
Michigan, US

Telescope: 12" Ritchey-Chrétien reflector and Takahashi E-180 Astrograph

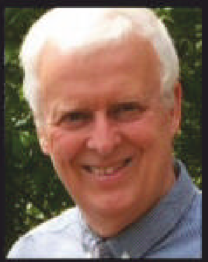
"My interest in astronomy and photography began some 40 years ago in Australia. Inspired by the late Sir Patrick Moore, my first telescope was a 4.5-inch Newtonian, and I enjoyed many nights in the pollution-free, dark southern night skies of the hot Australian outback. It was often so dark that the Milky Way cast a shadow on the ground.

"The skies are mediocre in western Michigan where I now observe from in the evenings. I pride myself in taking really long-exposure astrophotographs of deep-sky objects and always try to maintain a natural look."

The Cygnus Wall and North America Nebula (NGC 7000)



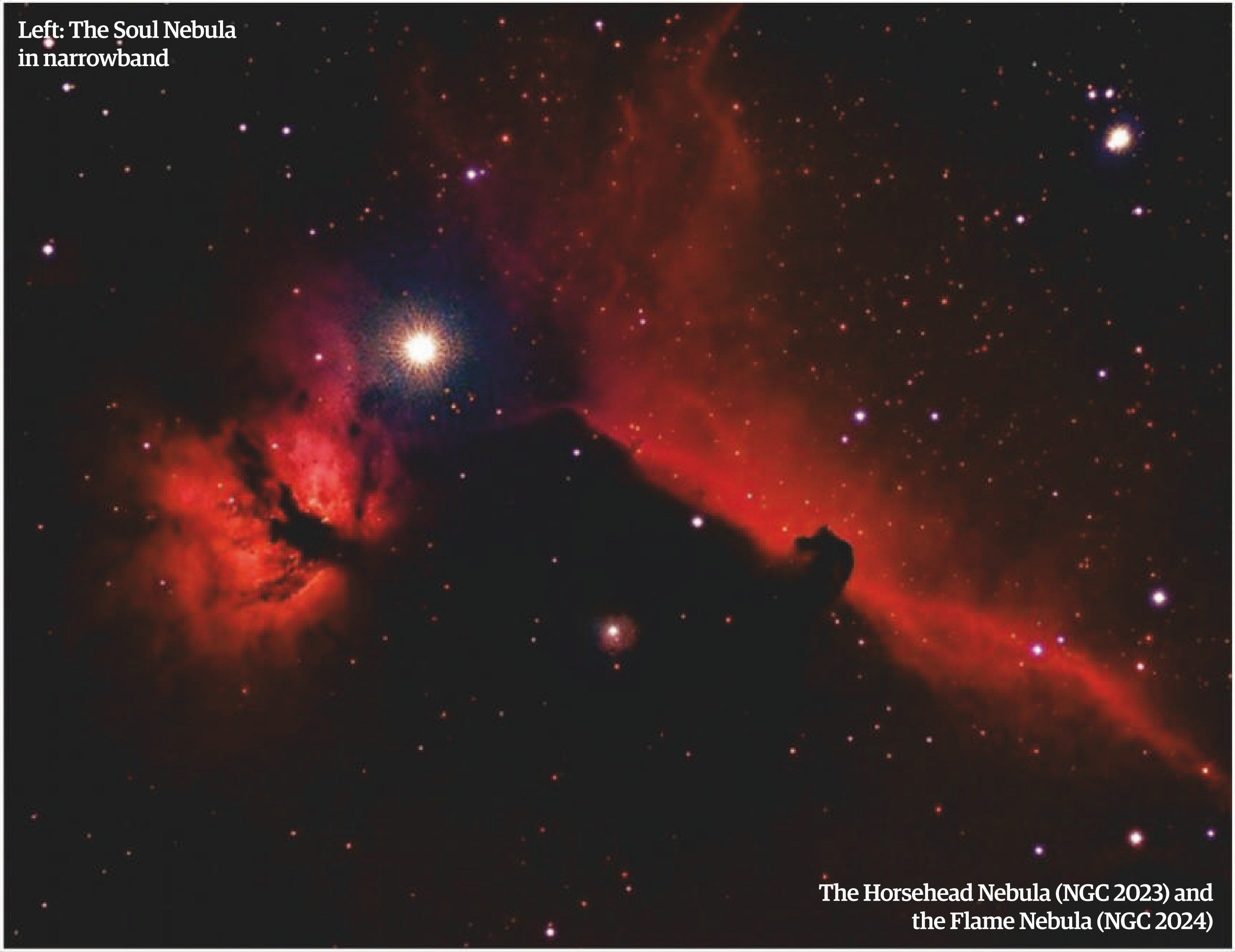
Graham Hard



London, UK

Telescope: Sky-Watcher Explorer-250PDS

"I took up astrophotography back in April 2012. I soon realised that galaxies, among other deep-space objects such as nebulae, are very limited when it comes to viewable detail. This led me to begin looking at photographing these objects. Now I will often collect image data exceeding 12 hours to produce my images. I love to shoot all aspects of the night sky: comets, planets, the Sun, the Moon and all galaxies and nebulae. Given that the night sky is poor where I live, I'm currently experimenting with narrowband imaging, which can improve the negative effects of light pollution with minimum effort."



Left: The Soul Nebula in narrowband

The Horsehead Nebula (NGC 2023) and the Flame Nebula (NGC 2024)

Send your photos to... @spaceanswers @ space@spaceanswers.com

Meade Wilderness 20-60x80

An instrument built to last, this spotting scope is perfect for the casual astronomer and wildlife watcher

Telescope advice

Cost: £210 / $257
From: Hama UK Ltd
Type: Spotting scope
Aperture: 80mm

Best for...

- Intermediate
- Medium budget
- Planetary viewing
- Lunar viewing
- Digiscoping

If you can't quite commit to a full-blown hobby in astronomy but enjoy watching nature at play, then a spotting scope in the Meade Wilderness range could be the instrument for you. From initial impressions the 20-60x80 is an excellent specimen, featuring a rugged rubber armour to protect the optics from moisture and finished to a high standard. The Meade Wilderness is supplied with a high-quality 20-60x zoom eyepiece, a soft case and camera adapter, but unfortunately doesn't come with a tripod - something that this spotting scope requires for stable observations. For this reason we think that the Meade Wilderness is suitable for those interested in casual astronomy and with a medium budget. If your budget is low, then we recommend taking the plunge and buying a telescope that's much more geared toward observing the night sky and comes equipped with accessories and a tripod.

Its waterproof design allows nature lovers to watch wildlife in a variety of weather conditions. For added protection the Meade Wilderness also features a nitrogen fog proofing inside the armour - something that observers of the night sky will appreciate. Astronomers know all too well about the condensation that a change in temperature can bring - like moving an observing instrument from the warm indoors to the much colder outdoors - which ultimately can cause damage to the objective lens' coating and the optical system in general. The Meade Wilderness ensures that condensation isn't a problem, allowing the skywatcher to enjoy a selection of targets fuss-free. The Meade Wilderness is coated in a generous amount of protective armour, but this doesn't hinder the exquisite lightness of the instrument that makes it ideal as a 'grab-and-go' scope for travel.

Spotting scopes are often overlooked - even for the most basic of astronomical observations - but the Meade Wilderness certainly got our attention; it was particularly useful when it came to observing the Moon, star clusters and the brighter naked-eye planets. The warmer summer skies of August offered a good selection of targets to test the

Above: The Meade Wilderness comes supplied with a 20-60x zoom eyepiece, which fits snugly to the main tube

Left: The eyepiece is angled at 45 degrees for a comfortable viewing experience

Right: The spotting scope is armoured with rugged, waterproof armour to protect the optics

Meade Wilderness' mettle. The spotting scope is easy to use, with no need for a finderscope to guide us to specific targets.

Saturn in the south got our immediate attention – the ringed gas giant is a particularly easy target to locate, and the Meade Wilderness provides clear and crisp views. We were able to make out the planet's rings, and while not as spectacular a sight as you'd get through a telescope with a medium-sized aperture, views of the planet through the Wilderness are satisfactory. We waited until the following evening to catch the Moon, which was at its first quarter, which provided excellent views of its cratered surface along the terminator. Operation of the zoom eyepiece is smooth, similar to the twist eyecup, which we noted to have very good eye relief that makes it suitable for those with or without spectacles. The angled orientation of the Meade Wilderness' eyepiece holder at 45 degrees made for very comfortable viewing. A multi-coated lens along with the BaK4 prism ensured clear and crisp views across a very good proportion of the field of view using the high-quality zoom eyepiece.

This spotting scope is limited to the brighter targets of the night sky. If nature-watching is of no interest to you or you are just learning your way around the night sky, we strongly recommend buying a pair of binoculars or a telescope that comes as a more complete package. If, on the other hand, you're looking for an instrument that's easy to carry and compliments your existing kit, then this rugged spotting scope is certainly worth a look.

> "The spotting scope is easy to use, with no need for a finderscope to guide us to specific targets"

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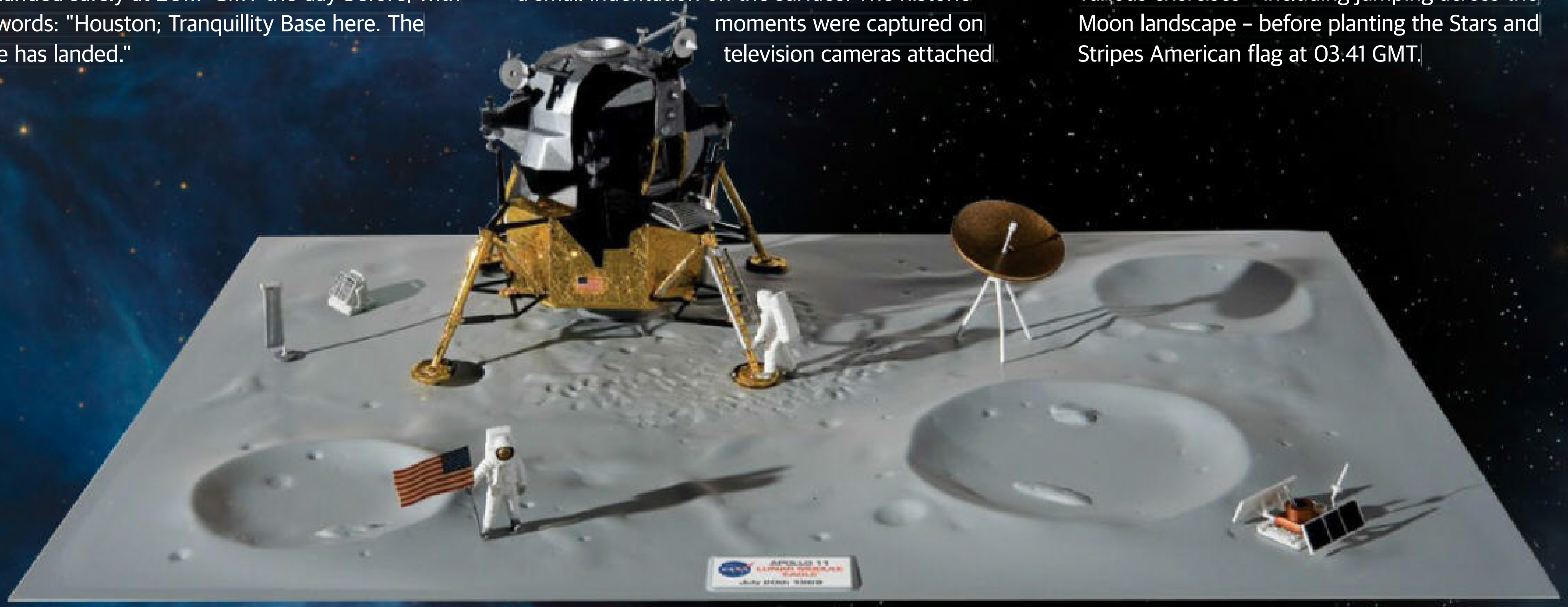
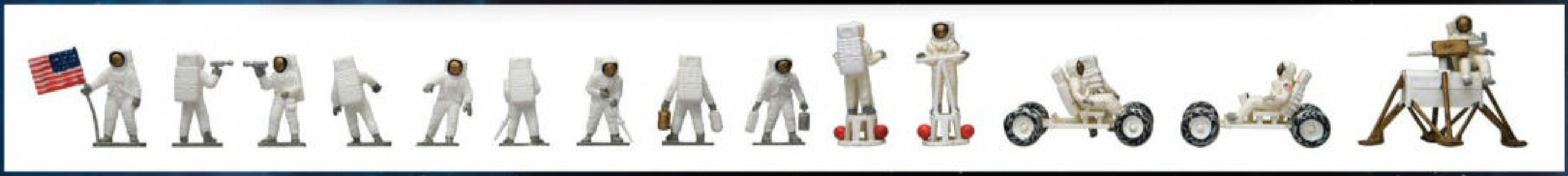
Courtesy of Hornby Hobbies, win one of ten sets and relive the real-life lunar landing

On 21 July 1969, American Neil Armstrong became the first man to walk on the Moon. The astronaut stepped onto the Moon's surface, in the Sea of Tranquillity, at 02.56 GMT, nearly 20 minutes after first opening the hatch on the Eagle landing craft. Armstrong had earlier reported the lunar module had landed safely at 20:17 GMT the day before, with the words: "Houston; Tranquillity Base here. The Eagle has landed."

As he put his left foot down first he made the iconic announcement: "That's one small step for man, one giant leap for mankind," which he said came to him without planning it ahead. He then went on to describe the surface as being like powdered charcoal, and the landing craft only left a small indentation on the surface. The historic moments were captured on television cameras attached to the Eagle and were switched on by Armstrong himself. He spent the first few minutes on the surface taking photographs and soil samples in case the mission had to be aborted suddenly. He was joined by his colleague Edwin 'Buzz' Aldrin at 03.15 GMT and the two collected data and performed various exercises – including jumping across the Moon landscape – before planting the Stars and Stripes American flag at 03.41 GMT.





To be in with the chance of winning, all you have to do us answer this question:

At which planet would you find the hexagonal polar vortex?

A: Saturn

B: Neptune

C: Jupiter

Competition ends on 5 October 2019

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Book

The Moon: A Celebration of Our Celestial Neighbour

Cost: £20.00 (approx. $24.40 / €22.05)
From: Collins

Our fascination with the Moon is intimately bound up with the development of human culture and civilisation. By studying and exploring the Moon we have come to understand more about our aspirations, as well as our dreams and ourselves.

Marking the 50th anniversary of Neil Armstrong's 'small step' and published to coincide with Royal Museums Greenwich's exhibition The Moon, this landmark work explores people's fascination with our only natural satellite. Edited by the exhibition's curators, Melanie Vandenbrouck, Megan Barford, Louise Devoy and Richard Dunn, this book illuminates how art and science meet in our profound connection with the Moon. It features authors from a variety of disciplines, including cultural historians, curators, a scientist, a poet and a space law expert, among others.

App

Space Junk Pro

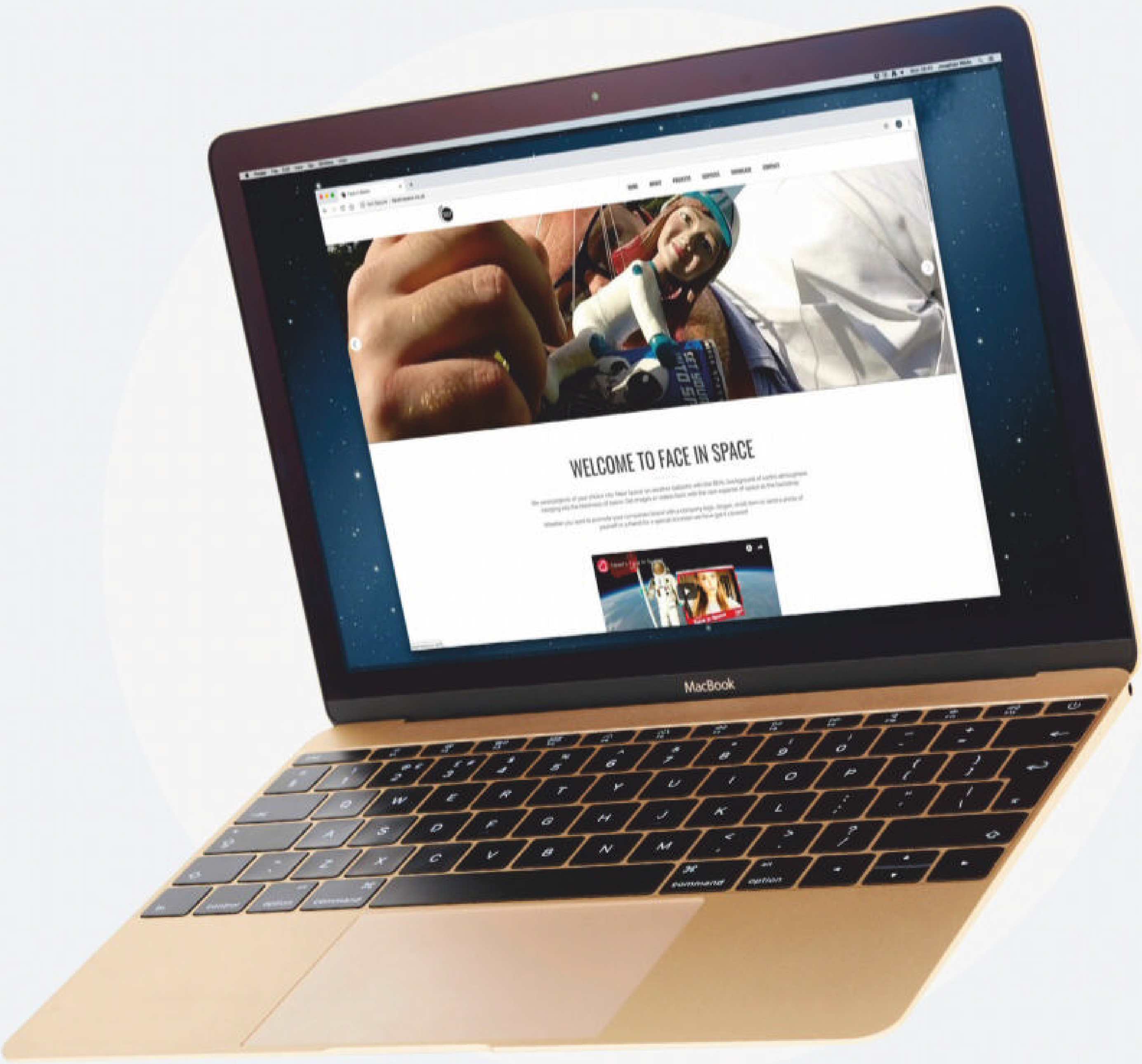
Cost: £2.99 / $4.69
From: Google Play and iTunes

We very much like the idea behind Space Junk Pro, which uses satellite data to show you which planet, satellite and constellation is viewable in your sky at any one time. What's more, this app is available for anyone who uses Android or iOS.

We were particularly impressed with the way in which Space Junk Pro was able to locate the International Space Station (ISS) and even the Hubble Space Telescope, making it a sure favourite for anyone who has ever found themselves rushing outside to witness the ISS racing around our planet in its orbit.

Smoothly uploading the app onto an iPhone and ensuring that our device's compass was calibrated, we found no issues with the running of Space junk Pro. However, we did find that it drains phone batteries quite quickly and automatically started up without prompting when we switched on our device. This might be off-putting for some, but overall the app is an excellent piece of software for a very good price.

All About Space EDITOR'S CHOICE



Space launch
Face in space

Cost: £999.00 (approx. $1214.19)
From: faceinspace.co.uk

Although developing your own spacecraft or getting yourself put on the next flight to the International Space Station is still exclusively within the pockets of multimillionaires, these days you don't have to have more money than you can spend to feel like you've escaped Earth.

Face in Space is the brainchild of aerospace industry veterans Chris and Dave, who have developed a more affordable way of getting a sentimental object or personal message into space, or at least near space. Whether you want to propose to your partner or send a fluffy toy into the stratosphere, Face in Space will strap a weather balloon to a payload that includes a photographic or video-capturing camera to snap your object as it ascends to the dizzy heights of 34,000 metres (110,000 feet) altitude. Face in Space can even put a customised, interactive launch together for you, though at the price of a high-end telescope rig, this package is more suited to corporate promotions than individual customers.

> “Face in Space can put a customised, interactive launch together for you”

Book
The Cosmos: Astronomy in the New Millennium

Cost: £51.99 (approx. $63.55 / €57.30)
From: Cambridge University Press

The Cosmos provides the reader with the fundamentals of astronomical knowledge that have been built up over decades, with an expanded discussion of the incredible advances that are now taking place in this fast-paced field, such as New Horizons' flyby of Pluto, exoplanets, dark matter, and the direct detection of gravitational waves by the Laser Interferometer Gravitational-Wave Observatory (LIGO).

Written in a clear and easily understandable style, this book has been thoroughly revised to include updated data and figures, new images from recent space missions and telescopes, the latest discoveries on supernovae and new observations of the region around the 4 million-solar-mass black hole at the centre of our Milky Way. A rich array of teaching and learning resources is available at **thecosmos5.com**. The website is regularly updated to include the latest discoveries and photographs in the field.

Michael Foale

This British-born astronaut has experienced the majesty and danger of space, having being involved in six spaceflights

Foale is a veteran of six spaceflights, totalling over 374 days in space

©NASA

Dr Michael Foale holds the record for most experienced British-born astronaut, having clocked up double the time in space that Tim Peake has accumulated thus far. Foale conducted vital Hubble repairs with NASA's Space Shuttle missions, life-saving repairs to Russia's Mir space station and even had a stint on the International Space Station.

He was born on 6 January 1957 in Louth, Lincolnshire, England, but has said that he considers Cambridge his hometown. He was well educated and eventually completed a doctorate in laboratory astrophysics in 1982 from Queens' College, Cambridge, which he attended at the same time as actor Stephen Fry. He was also a member of the Air Training Corps while studying in Cambridge.

Foale had his sights set on a career in the United States space programme, however, so a few years after picking up his doctorate, Foale moved to Houston, Texas, and worked at the NASA Johnson Space Center in the payload operations department. It was 1987 that saw him finally selected as an astronaut candidate. This induction was the start of an impressive astronautic career that could easily deem Foale an unsung hero of spaceflight.

The first of his missions came in March 1992 as he flew as a mission specialist on the STS-45 mission. A year later saw him fly in the same role on the STS-56 mission, and another came in February 1995 as part of STS-63, which performed the first rendezvous with the Russian Space Station, Mir.

In May 1997 Foale made the journey to space once again, but for a much longer stay on board Mir. For four-and-a-half months Foale performed science experiments as well as repairing malfunctioning systems on board the station, but his most notable contribution was a six-hour extravehicular activity that was spent repairing the station's Spektr module after damage was caused by a collision with a Progress resupply ship.

He flew his final Space Shuttle mission in December 1999, which saw him spend eight days in space repairing the revered Hubble Space Telescope. He and his team installed new instruments and upgraded the systems, which are still bringing us marvellous sights from the depths of the cosmos 20 years later.

In 2003 Foale launched on a sixth and final mission to the International Space Station for Expedition 8, accompanied by Russian cosmonaut Aleksandr Kaleri. After six months aboard humanity's most creative and valuable research station, Foale had accumulated over 374 days in space - with over 16 hours of that being spacewalks. He has since been inducted into the United States Astronaut Hall of Fame and was awarded a CBE in 2004.

> "Foale had his sights set on a career in the United States space programme, however, so he moved to Houston, Texas"

All About Space

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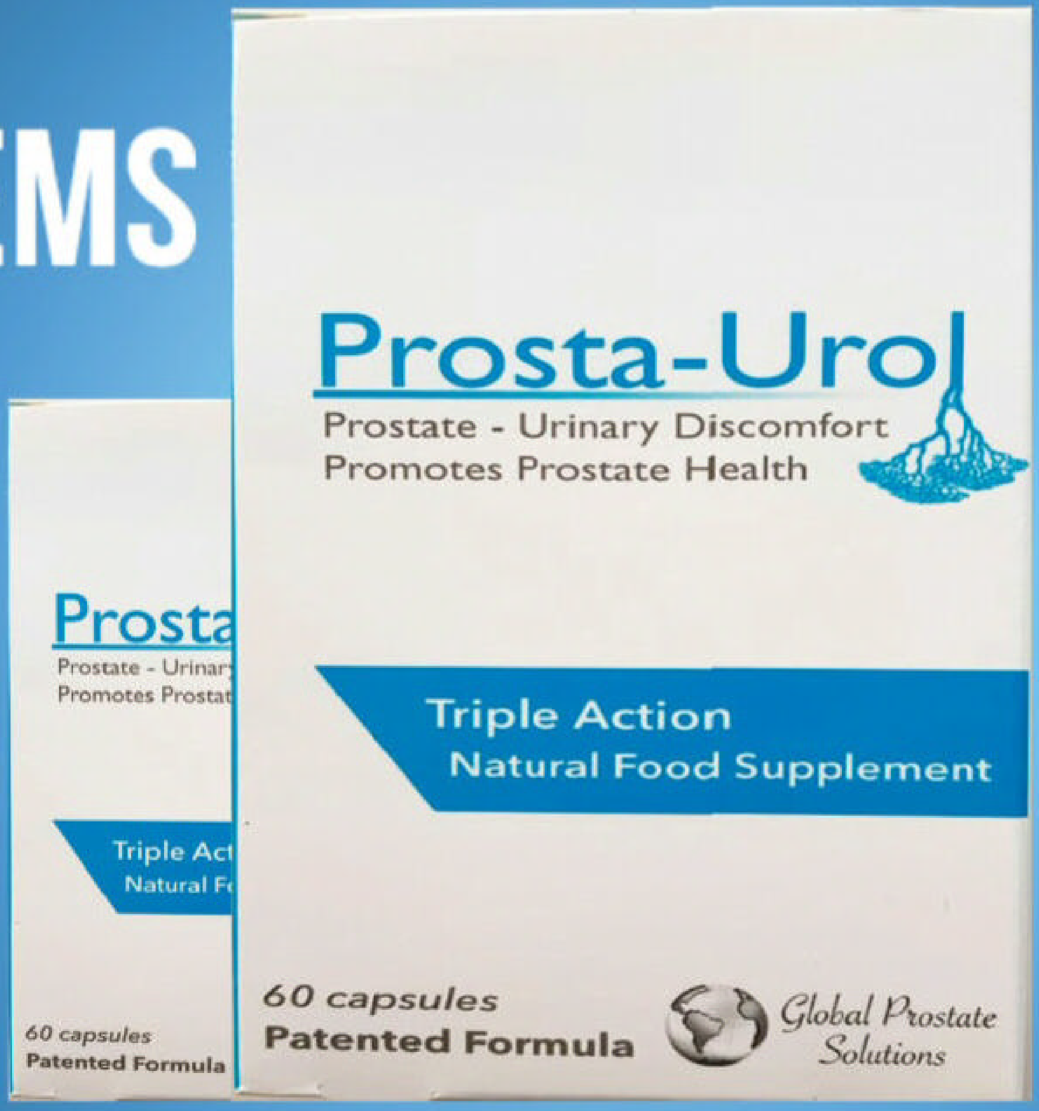

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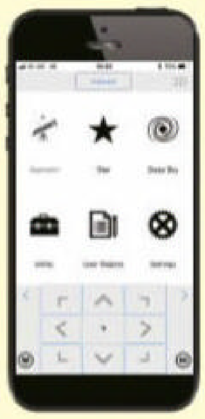
- SynScan™ App Alignment Method: Brightest Star Alignment, North-Level Alignment
- SynScan™ App's Other Features: Tonight's Best Sky Tour, Point and Go with a mobile device, Identification of Celestial Objects, Remote control over Internet, User defined objects, Pointing Accuracy Enhancement (PAE)

Wi-Fi

SYNSCAN™ GO-TO



AZ-GTe, AZ-GTi & STAR DISCOVERY Wi-Fi GO-TO TELESCOPES

These telescopes have been designed to be controlled wirelessly with your Smartphone or Tablet, using the free SynScan™ App for iOS or Android. The mounts create their very own Wi-Fi network, so the mount can be used anywhere, without any reliance on other Wi-Fi networks. After entering your coordinates into the App and following a simple alignment procedure, you are ready to explore the universe using the App's intuitive touchscreen menu. The SynScan™ App provides full computerised GO-TO control, allowing your telescope to be automatically slewed to any one of the objects in the App's extensive database of 10,000+ celestial objects. The AZ-GTi and Star Discovery mounts incorporate Freedom-Find™ dual-encoders, allowing them to be moved manually without losing their alignment or positional information. All models also compatible with optional Synscan™ Handset and Cable code 20948/20160.

MERCURY-707 (AZ-GTe)
70mm (2.75") F/10 Wi-Fi GO-TO REFRACTOR
SRP £345

SKYHAWK-1145PS (AZ-GTe)
114mm (4.5") F/4.4 Wi-Fi GO-TO PARABOLIC NEWTONIAN
SRP £345

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STARTRAVEL-102 (AZ-GTe)
102mm (4") F/4.9 Wi-Fi GO-TO REFRACTOR
SRP £395

Wi-Fi

SYNSCAN™ GO-TO

Wi-Fi

SYNSCAN™ GO-TO

FREEDOM FIND™

EXPLORER-130PS (AZ-GTi)
130mm (5.1") f/5 Wi-Fi GO-TO PARABOLIC NEWTONIAN
SRP £415

SKYMAX-102 (AZ-GTi)
102mm (4") f/12.7 Wi-Fi GO-TO MAKSUTOV-CASSEGRAIN
SRP £435

SKYMAX-127 (AZ-GTi)
127mm (5") f/11.8 Wi-Fi GO-TO MAKSUTOV-CASSEGRAIN
SRP £549

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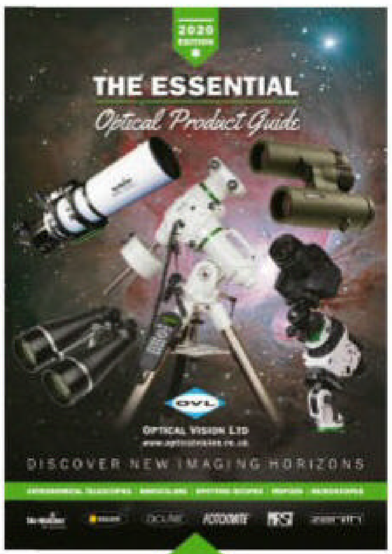
STAR DISCOVERY 90i
90mm (3.5") f/10 Wi-Fi GO-TO REFRACTOR
SRP £435

STAR DISCOVERY P150i
150mm (6") f/5 Wi-Fi GO-TO PARABOLIC NEWTONIAN
SRP £459

Wi-Fi

SYNSCAN™ GO-TO

FREEDOM FIND™



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